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The Cover

Not a lobster, but electric breakdown progressing through a rock-salt crystal, as seen by a visual method which gives a new insight into the breakdown mechanism of solid and liquid insulation

Photo courtesy A. von Hippel (M'37)

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High Lights

Earnings of Engineers. Statistics based upon monthly earnings of engineers suggest conclusions different from those deduced by an analysis of the annual earnings. A continuation of a comprehensive survey of employment in the engineering profession shows marked differences in earnings within each professional class, and within each group classified on the basis of educational background (*pages 1450–60*).

Winter Convention. An enlarged program will feature the AIEE 1938 winter convention to be held January 24–28 in New York, N. Y. Tentatively, 66 papers have been scheduled to be discussed in 16 technical sessions. The program will include also several addresses and technical conferences, and a post-convention cruise to Bermuda (*pages 1516–17*).

Co-operation Among Societies. Two years of successful operation attest to the effectiveness of the co-operative action that resulted in the organization of the Technical and Scientific Societies Council of Cincinnati, Ohio, which brings together ten organizations comprising some 1,500 members (*pages 1525–6*).

Trolley-Coach Operation. The so-called "trackless trolley" has been adopted for public transportation in more than 30 cities in the United States, and in Europe. Some operating experiences with trackless trolleys on systems situated on opposite sides of the United States have been summarized and are presented in two papers in this issue (*pages 1461–3 and 1483–6*).

Oil Oxidation. Separate studies of the effect of equal amounts of air and of nitrogen in cable paper impregnated with oil, of the oxidation behavior of the oil alone and as affected by paper and metal, produce new information regarding the progressive changes of electrical characteristics of oil-impregnated cables (*pages 1492–1501*).

American Engineering Council. Recommendations for a public works department, and discussions of mapping by government agencies and of scientific research legislation now under consideration by Congress were included in the current "News Letter" of American Engineering Council (*pages 1526–7*).

The Dielectric Circuit. Electrostatics and the theory of the dielectric circuit frequently are confusing to students of electrical engineering. A teacher, who is renowned among his own students for his ability to make abstruse subjects lucid, has presented the fundamentals of dielectric-circuit theory in graphic style (*pages 1434–40*).

Institute Directors Meet. At the October 28 meeting of the AIEE board of directors, the budget for the year 1937–38 was adopted, representatives on joint organizations and committees were appointed, a revised publication policy was adopted, and other questions of importance to the membership discussed (*page 1518*).

1937 Index 1537

On the 20 pages beginning with page 1537 of this issue is published the annual reference index, listing some 2,200 entries, covering all text material published in ELECTRICAL ENGINEERING during 1937. Special information regarding the index is given on page 1537.

Insulation Committee Meets. The tenth annual meeting of the committee on electrical insulation of National Research Council was characterized by the usual spontaneous and informal discussion, and reflected the continuing advance of research in dielectrics (*pages 1520–2*).

United Engineering Trustees. Officers were elected and annual reports presented at the annual meetings of United Engineering Trustees, Inc., and the Engineering Foundation; the annual report of the Engineering Societies' Library also was presented (*pages 1527–30*).

Stray-Load Losses. A method of measuring the stray-load losses of d-c machines, which is described in a paper in this issue, is adaptable to the testing departments of manufacturers, and requires no special equipment (*pages 1487–91*).

Switching Surges. The magnitude and characteristics of abnormal voltage transients accompanying operation of load-ratio control cotractors on power transformers have been studied both experimentally and theoretically (*pages 1464–75*).

Telephone Research. Transmitters and receivers have been developed to their present high quality by research which includes an extensive analysis of the composition of speech sounds and the study of hearing (*pages 1441–8*).

Exposition Lighting. Plans for the illumination of the Golden Gate Exposition in 1939 reveal the large part that lighting will play in novel forms at this $50,000,000 fair (*page 1449*).

Institute Budget. The AIEE budget, as adopted by the board of directors for the year 1937–38, provides for a broadening of several essential services to the membership (*pages 1433; 1522–4*).

Noble Prize Awarded. For the third time since its establishment in 1931, the Alfred Noble prize has been awarded to an AIEE member (*page 1519*).

Multiple Unbalances. The solution of a network containing a multiple unbalance may be simplified by the use of a network analyzer (*pages 1476–82*).

Letters to the Editor. A rotor-flux-locus concept of single-phase induction-motor operation is discussed in this month's "Letters" section (*page 1531*).

New AIEE Section. The Institute's 64th Section recently was organized at Tulsa, Okla. (*page 1518*).

DISCUSSIONS

Appearing in this issue are discussions of the following papers:

Statements and opinions given in articles and papers appearing in ELECTRICAL ENGINEERING are the expressions of contributors, for which the Institute assumes no responsibility. Correspondence is invited on all controversial matters. ¶ Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the fifteenth of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London).

Number of copies this issue—21,800.

The AIEE 1937-38 Budget

To the Membership:

AT ITS MEETING on October 28 your board of directors adopted the budget for the year ending September 30, 1938, the details of which are covered on pages 1522–4. There are some phases of the board's consideration of the budget which seem of special interest.

The broad operations of the Institute have been conducted in an excellent manner and the modest surplus accumulated over a period of years shows an encouraging trend—a commendable showing especially as the essential services to the membership have been maintained at a satisfactory level. A few years back, here and there some curtailment of expenditures was necessary; but through constructive co-operation and sympathetic understanding of the membership at large, interest in the affairs of the Institute was sustained and activities broadened, even during these years.

President Harrison

The budget for the current year assumes that revenues will increase $10,000 as contrasted with last year and that expenditures will increase $30,000 over the same period. Total revenues are expected to be $299,500 and expenses $299,000—practically nothing to be carried over to surplus.

Some in the membership may question the wisdom at this time of planning expenditures on such a liberal basis and so close to the estimated income. The board recognized this but thought it proper, all things considered, to broaden several of the essential services. With the interest of the membership so great, and with so much voluntary effort being expended in behalf of the work of the Institute, it seemed clear that increased appropriations for some activities would produce substantial benefits.

In considering the expenditures it will be realized how well they are directed toward the fulfillment of the two objectives for which the Institute was created and exists: ". . . the advancement of the theory and practice of electrical engineering and of the allied arts and sciences and the maintenance of a high professional standard among its members." A considerable part of our activity centers about our publications and meetings. These activities not only satisfy the first objective but, in addition, the free interchange of information and the personal contacts which they provide are an important contribution toward the second objective. More money will be spent this year than last on publications and on national, District, Section, and Branch meetings. It is interesting to note that what we pay for is the machinery by means of which we receive a continuous flow of invaluable information and, in turn, impart to our fellow members information of value which we possess. We pay nothing for the information—we pay only for the paper, the printing, the meeting places, and the other means through which we obtain and discuss the information conveniently. A new publication policy which is to be put into practice next month and which is expected to make the publications of even greater value, already has been described in the November issue of ELECTRICAL ENGINEERING.

The Institute's objectives are also advanced through the contributions made for the support of the American Engineering Council, the Engineers' Council for Professional Development, the American Standards Association, the Engineering Societies' Library, and similar organizations through which the Institute co-operates with other national engineering societies in considering and acting on matters of common concern to the engineering and allied technical professions.

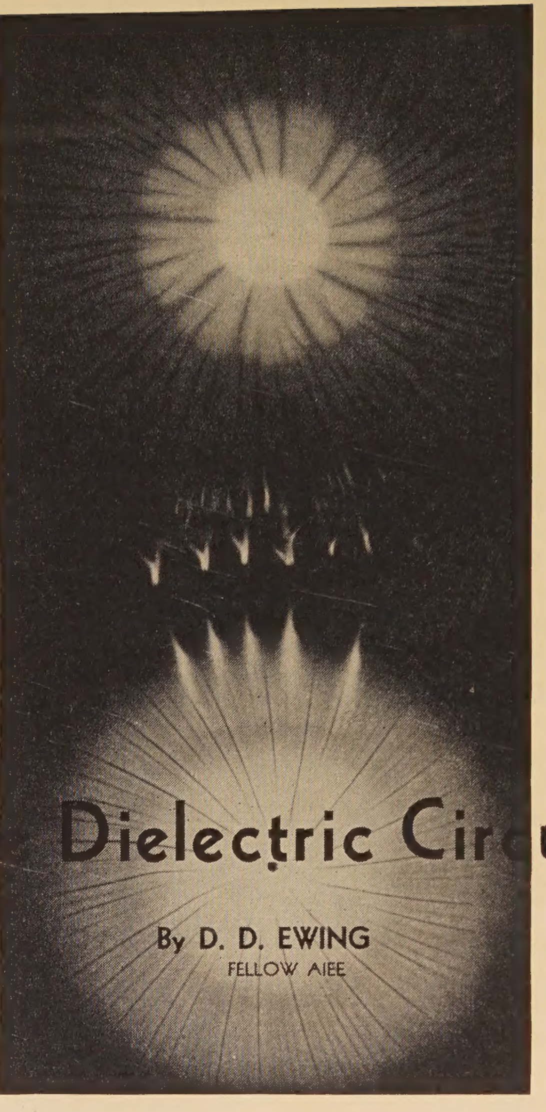
Every member of the Institute will get something of value from the sum total of expenditure no matter where he may be located. However, it is those who actively take part in the Branch, Section, and other Institute affairs who will get the greatest value. Let each of us read the publications, go more often to meetings, enter more actively into the discussions of talks and papers, and participate in the business of the committees to which we may belong. We will find that there is hardly an activity of any kind within the scope of the professional interests of an electrical engineer in which the Institute is not engaged through its committees and relations with other bodies.

We have undertaken an ambitious budget of expenditures. Your board is mindful too that still further expenditures could be made to advantage. Our principal source of income is from members in the form of dues. To assure the carrying out of this year's program and to make possible an ever broadening range of desirable activities, an increase in membership rolls is essential. Consideration of the budget makes this evident. I earnestly ask your continuing support toward this end.

C. H. Harrison

PRESIDENT AIEE

The Dielectric Circuit



By D. D. EWING
FELLOW AIEE

The dielectric circuit is a baffling enigma to many undergraduate students of electrical engineering; indeed, to many engineers whose work is not intimately concerned with it. This outline of some of the elementary notions regarding electrostatics and the dielectric circuit is presented here because of its possible interest and value to students and others wishing to review the subject with the aim of attaining a working knowledge of it.

THERE IS AN ancient proverb that says in part: "he who is first shall be last." This phrase seems to have some application to the subject of electrostatics. Until Galvani and Volta made the discoveries that "galvanized" the subject of electrodynamics into life, at about the same time the present form of constitutional government was being born in the United States, the world's knowledge of electricity, and its effects, was confined pretty much to the subject of electrostatics. The versatile and questioning Franklin made many forays into this field of thought and his feat of flying a kite during a thunderstorm is known to every school boy. But with the discovery of the voltaic cell in the passing days of the eighteenth century came the great developments in the field of electrodynamics, which for a century completely overshadowed almost everything pertaining to the subject of electrostatics. True, lightning remained as a manifestation of natural electrostatic activity, and some use was found for capacitors and similar electrostatic apparatus, but a general interest in electrostatics and the dielectric circuit was quickened only when such interest was demanded by the more complex problems in telephony and radio, and by the insulation and other electrostatic problems associated with high-voltage apparatus.

Few indeed were the electrical-engineering curricula that contained any but the most meager courses of instruction in electrostatics 25 years ago; but today this neglect is not so general. As students in physics and in beginning courses in electrical engineering most of the readers of this article devoted some little time to studies of the dielectric circuit. Unfortunately it seems to be a subject about which the average seniors in electrical engineering—yes, even most of the engineers engaged in the ordinary routine work of the electrical engineer—have almost unlimited powers of forgetfulness. In the hope of paving the way, as it were, for a flying start in further studies of transmission lines and problems concerning high voltages this brief review of some of the elements of electrostatics and the dielectric circuit has been prepared.

In the space available it is not possible to give credit to all those deserving it. Also, from a strictly rigorous point of view, some readers may wish to question the methods and the accuracy of some of the illustrations used in this review. Be that as it may, the immediate object is to arrive at a reasonable working knowledge of the dielectric circuit, and the finer distinctions may well be left for argument at some other time.

For convenience, and for the purpose of securing a bird's eye view of the realm of electrostatics, the accompanying "tabloid" presentation of the subject has been arranged.

As a foundation for this discussion, almost all knowledge of the dielectric circuit may be said to be based upon the 5 fundamental laws contained in the first "box" of the tabloid presentation. Now these "laws," as most readers well know, are not written on the statute books of this or any other country. They are compilations of bits of fundamental truth refined from the elementary discoveries of many investigators. They are all based on knowledge experimentally determined. Whether or not they may be determined by rational processes instead of experimentation is a subject that is left to the physicists. For the present these laws will be considered "constitutional," at least until thrown aside by the high court of rigorous scientific research.

Written especially for ELECTRICAL ENGINEERING, this article presents the essence of a review lecture delivered by the author to a group of senior electrical-engineering students at Purdue University.

D. D. EWING is professor of electrical engineering at Purdue University, Lafayette, Ind. A native (1883) of Vanlue, Ohio, he was graduated in electrical and mechanical engineering from Ohio Northern University in 1906, following which he spent a year in telephone and railway work. In 1907 he was appointed to the faculty of Ohio Northern University as professor of electrical and mechanical engineering, and remained in that position until 1913, when he became assistant professor of electrical engineering at Purdue University. Subsequently he became associate professor, and received his full professorship in 1918. Besides his regular teaching duties, Professor Ewing has devoted much time to consulting engineering work. He is co-author of a textbook and author of many papers on electric railway engineering. He has been a member of the Institute's committee on electric welding since 1932, and is a member of the committees on power transmission and distribution, and transportation.

These basic principles are, or should be, well known to everyone who has studied even an elementary course in physics. Misunderstanding comes when one desires to make use of this basic knowledge in the solution of the practical problems with which the engineer is familiar as part of his daily routine of duties.

The first law, namely, the law of electrostatic attraction, or repulsion, has been known for many years. The language and symbolism used in describing this law are, of course, recent; but the basic idea has been known for ages. Probably some cave-man ancestor of ours discovered it on a frosty day long ago when he stroked the back of some member of the cat family, which he was trying to tame. Thales, the Greek, wrote of the effect of rubbing amber in 600 B.C. and possibly others had noticed the effect and even written about it long before the time of Thales.

Coulomb, a contemporary of Washington and Franklin, making use of the first law, discovered the second law, which bears his name. The third law is not as well known as Oersted's discovery of a similar principle in electromagnetics but is just as true. Many readers have witnessed its demonstration—the usual procedure being to energize at high voltage a wire projecting upward through a horizontal pane of glass. Mica chips or bits of cotton lint scattered over the glass promptly arrange themselves in radial lines as shown in figure 1. The arrowheads in these figures indicate the direction of force action.

That the forces of electrostatic attraction, or repulsion, are greater in some media than in others was known to several of the earlier investigators in electrical science. In some dielectrics a given charge of electricity may produce from one to 10 times the force action that is produced in air (see the fourth law).

Like the law of attraction, or repulsion, the law of electrostatic induction (fifth law) has been known, in effect at least, for many years. Its scientific observation and formulation, however, belong to a more recent date. Other laws and effects of importance might be enumerated, but at the moment and for the present purpose, the groups of discoveries formulated in the "box" of basic laws seem most important. From these experimental laws several concepts and definitions have been set up by the physicists. These are necessary in order that the engineer may be able to formulate his problems in electrostatics. By way of illustration the basic laws might be likened to the primary roots of a great tree as shown in figure 2. Growing out of these roots comes the "trunk" of definitions and concepts, and out of the trunk grow the ideas and formulas needed in the specific fields of practical application. The most useful of these concepts are placed in the second "box."

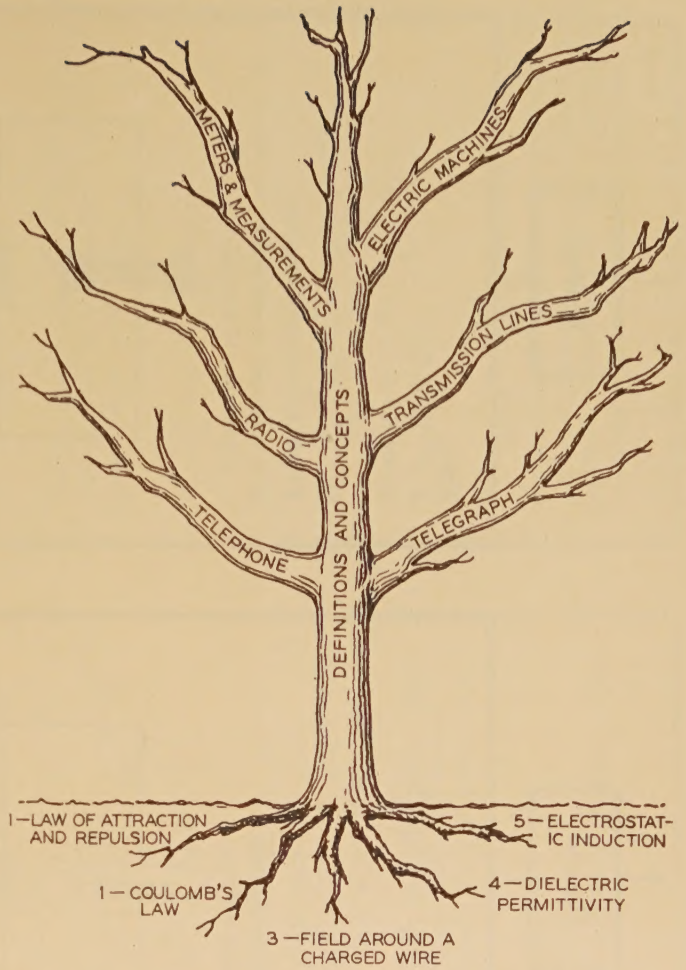


Figure 2. The "tree" of dielectric laws and concepts

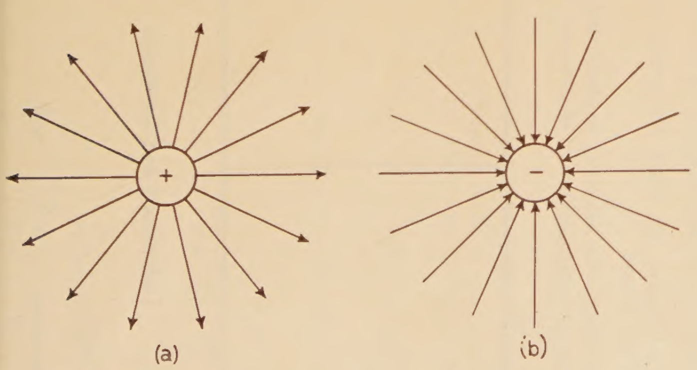


Figure 1. Sketch of the dielectric flux lines around conductors carrying current

(*a*)—Electrically positive conductor
(*b*)—Electrically negative conductor

The unit-charge concept comes directly from the first 2 laws, a unit charge of electricity being assumed to be of such magnitude that 2 similar unit charges placed one centimeter apart would repel each other with a force of one dyne. Here everything, it will be noted, is on a "unit" basis.

In order to determine the "strength" g of a given field at a specified point, someone had the happy thought of placing a unit charge at that point and measuring the resulting force action. This concept of *field intensity* is based on the second law and is most useful in the formulation of problems, although no one ever attempts in a practical way to measure a unit charge, place it in an electrostatic field, and then with some sort of spring scale or balance measure the resulting force action.

Electrostatics and the Dielectric Circuit

5 Basic Laws

1. Unlike charges attract; like charges repel.
2. The force of attraction (or repulsion) varies directly as the product of the charges and inversely as the square of the distance between them (Coulomb's Law: $F = q_1q_2/r^2$).
3. A charged wire is surrounded by an electrostatic field.
4. Some substances are more susceptible to electrostatic forces than are others.
5. A conducting body placed in an electrostatic field undergoes a change in potential (law of electrostatic induction).

Definitions and Concepts

1. Unit charge.
2. Field intensity: $g = \dfrac{q \times 1}{r^2} = \dfrac{q}{r^2}$

Physicist

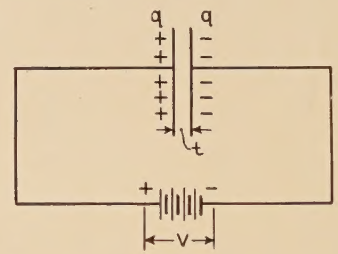
Tools

$g = D/K \qquad g = \dfrac{dE}{dr}$ or $\dfrac{dV}{dr}$

$q = VC \qquad D = \Psi/A \qquad \Psi = 4\pi q$

EXAMPLE 1—PLATE CAPACITOR

A = total area of one plate
t = thickness of dielectric



Assume q units of charge on each plate; then $D = 4\pi q$, but $g = D/K = 4\pi q/KA$. Also $V = gt$ (see eighth concept); therefore, $g = V/t$ and

$$\frac{V}{t} = \frac{4\pi q}{KA} \quad \text{or} \quad V = \frac{4\pi qt}{KA}$$

But $V = q/C$ and $C = q/V$; therefore,

$$C = \frac{KA}{4\pi t} \text{ statfarads}$$

EXAMPLE 2—FIELD AROUND A CONDUCTOR

This method may be used for computing the potential difference between 2 concentric surfaces of radii r_1 and r_2 about the conductor. Let q be the charge per centimeter of length of conductor. Then $\Psi = 4\pi q$ (fifth concept). At a radius of x centimeters

$$D = \frac{4\pi q}{2\pi x} \text{ (sixth concept); then } D = 2q/x.$$

But $g = D/K$; therefore,

Engineer

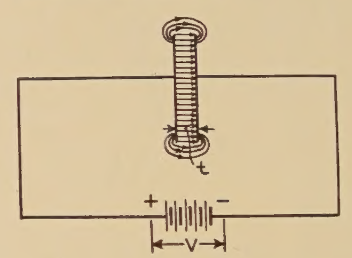
Tools

$\Psi = V/S$ or $E/S \qquad C = \dfrac{1}{4\pi S}$

$S = l/KA$

EXAMPLE 1—PLATE CAPACITOR

A = total area of one plate
t = thickness of dielectric



First determine the elastance. This can be written at once, as

$$S = \frac{l}{KA} \text{ and } C = \frac{1}{4\pi S}$$

therefore

$$S = \frac{t}{KA}$$

because t is the length of flux path, and

$$C = \cfrac{1}{4\pi \cfrac{t}{KA}} = \frac{KA}{4\pi t} \text{ statfarads}$$

EXAMPLE 2—FIELD AROUND A CONDUCTOR

This method may be used for computing the potential difference between 2 concentric surfaces of radii r_1 and r_2 about the conductor.

If $S = l/KA$, in this case dS is

$$dS = \frac{dx}{2\pi Kx} \text{ per centimeter length of conductor.}$$

6. Flux density: $D = Kg;\ D = \frac{\Psi}{A}$

7. Electrostatic potential:

$$E = \int_r^\infty g dr$$

where $g = f(r)$; that is, if $=g\ q/r^2$, then

$$E = \int_r^\infty \frac{q}{r^2}\, dr = \frac{q}{r}$$

8. Voltage = difference of potential $= V = \int_{r_1}^{r_2} g dr$

and $g = \frac{dV}{dr}$ or $dV = g dr$

For a flux path of uniform area $V = gl$, where l = length of path. Since $V = gl$ and $g = D/K$,

$$V = \frac{Dl}{K} = \frac{ADl}{KA}$$

therefore

$$V = \Psi \frac{l}{KA} = \Psi S$$

where $S = \frac{l}{KA}$

$$\frac{V}{S} = \Psi$$

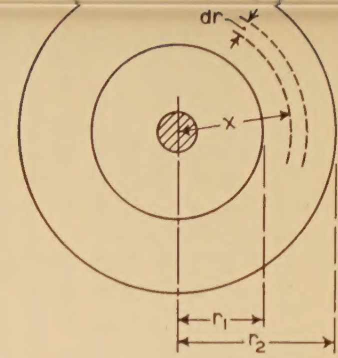
9. Unit capacitance: $V = q/C;\ C = q/V;\ q = VC$, where V is the voltage impressed on capacitance C. Since $\Psi = 4\pi q$, $\Psi = 4\pi CE$ or $4\pi CV$; therefore,

$$\frac{V}{S} = 4\pi CV \quad \text{or} \quad S = \frac{1}{4\pi C}$$

and

$$C = \frac{1}{4\pi S}$$

where C is the capacitance in farads

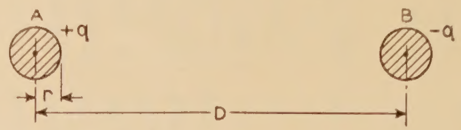


Integrating,

$$V_{r_1-r_1} = \frac{2q}{K} \log_e \frac{r_2}{r_1} \text{ statvolts}$$

which is the voltage between the 2 surfaces.

Example 3—Line-to-Neutral Capacitance in a Single-Phase Circuit



V_{AB} = voltage between lines. Using the relations from the 2 previous examples,

$$V_{AB} = \int_r^D 2q \frac{dx}{x} - \int_r^D -2q \frac{dx}{x}$$
$$= 4q \log_e (D/r)$$

remembering that in air $K = 1$. But

$$C = \frac{q}{V} = \frac{q}{4q \log_e (D/r)} \quad \frac{1}{4 \log_e \frac{D}{r}} \text{statfarads}$$

which is the line-to-line capacitance. Since the line-to-neutral capacitance is twice the line-to-line capacitance, the line-to-neutral capacitance is

$$C_A = \frac{1}{2 \log_e (D/r)}$$

statfarads per centimeter of length of the conductor.

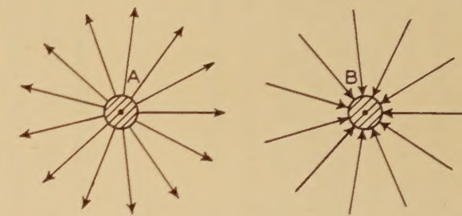
$$V_{r_2-r_1} = \frac{\Psi}{2\pi K} \log_e \frac{r_2}{r_1}$$

Since $\Psi = 4\pi q$,

$$V_{r_2-r_1} = \frac{4\pi q}{2\pi K} \log_e \frac{r_2}{r_1} = \frac{2q}{K} \log_e \frac{r_2}{r_1} \text{ statvolt}$$

which is the voltage between the 2 conductors.

Example 3—Line-to-Neutral Capacitance in a Single-Phase Circuit



Let r = radius of conductor. Using the relations for the 2 previous examples,

$$V_{r_2-r_1} = \frac{\Psi}{2\pi K} \log_e \frac{r_2}{r_1}$$

Then the absolute potential of conductor A is (that is, when $r_2 = \infty$ and $r_1 = r$, $V_{r_2-r_1}$ becomes equal to this value)

$$E_A = \frac{\Psi_A}{2\pi} \log_e \frac{\infty}{r} + \frac{\Psi_B}{2\pi} \log_e \frac{\infty}{D}$$

But $\Psi_A + \Psi_B = 0$ and also $\Psi_A \log_e \infty + \Psi_B \log_e \infty = 0$; therefore

$$E_A = \frac{\Psi}{2\pi}\left(\log_e \frac{1}{r}\right) - \log_e \frac{1}{D}\Big) = \frac{\Psi}{2\pi} \log_e \frac{D}{r}$$

But $E_A = \Psi S_A$; therefore,

$$\frac{1}{2\pi} \log_e (D/r) = S_A$$

$$C_A = \frac{1}{4\pi S_A} = \frac{1}{2 \log_e (D/r)} \text{ statfarads}$$

the line-to-neutral capacitance per centimeter length of conductor. E_A is the absolute potential of conductor A (line-to-neutral volts), and S_A is the line-to-neutral elastance.

Whatever the invisible and mysterious thing is that surrounds a charged wire produces force action on electric charges. To assist in the visualization of this phenomenon Faraday's concept of lines of flux may be used, drawing a line per square centimeter for each dyne of force action (third concept). Since at any point distant one centimeter from a unit charge concentrated in a point the force is one dyne, and since a sphere of unit radius has an area of 4π square centimeters, it follows that the field around a unit charge may be represented by 4π lines of flux, the lines radiating from the charge like the spines of a sand bur (concept number 4). If, instead of a unit charge, the charge be of q units, the total flux will be $4\pi q$ lines and the flux density (concept number 6) will be the total flux Ψ divided by the area, or $D = \Psi/A$ lines per square centimeter. D, it will be noted from the previous discussion is equal numerically to the number of dynes of force acting on a unit charge in air and in this case is also numerically equal to g.

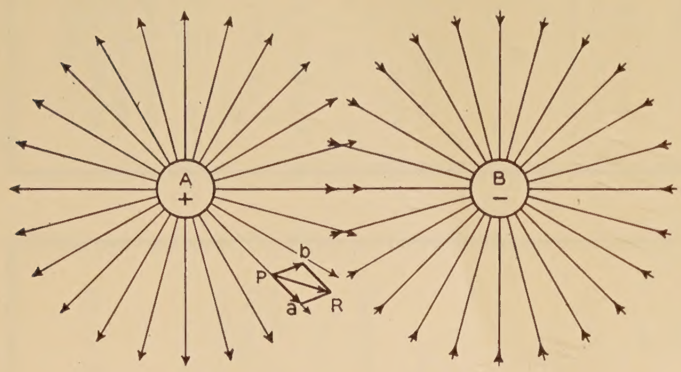


Figure 3. Sketch of the component fields surrounding the conductors of a single-phase circuit

In certain media a given charge of electricity produces more force action than does the same charge in air. To illustrate, the charge that will produce a field intensity of g and a flux density of D in air will produce K times this flux density in a specific medium. This, of course, is an exemplification of the fourth basic law. The factor K is called the dielectric constant and corresponds to specific conductivity in the electric circuit and to permeability in the magnetic circuit (as $B = \mu H$). It is apparent from this discussion that the dielectric constant of air is unity. Someone who wishes to attain fame might achieve his wish if he were to discover some natural or synthetic material of which the dielectric constant is as much greater than the dielectric constant of air as the permeability of even a low grade of steel is greater than the permeability of air.

When a one-pound weight has been lifted through an elevation of 10 feet, 10 foot-pounds of work has been done. That is, the work done is equal, *numerically* in this case, *to the elevation*. This simple deduction produces an idea: The height of a mountain could be measured by determining the amount of work done in elevating a given mass from the datum plane to the summit of the mountain. Not a very good idea, the reader may say, because no good instrument for measuring the work is available. The idea is all right but the trouble is in the instrumentation. Now this idea may be used in both magnetics and electrostatics in measuring "elevation." The "elevation" (electric potential) of a charge is measured as *numerically* equal to the work done in carrying a unit charge from infinity (the "sea level" or absolute datum plane of electric potential) to the point at which the potential is to be determined. Expressing this mathematically,

$$E = \int_r^\infty g\, dr$$

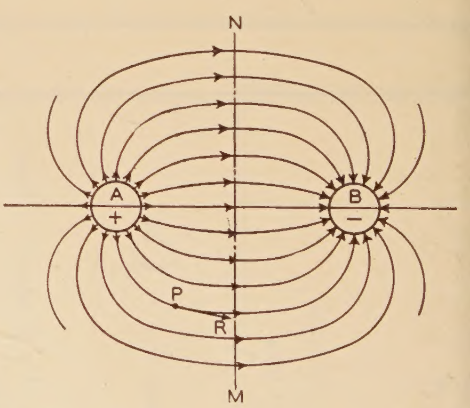
where g is the field intensity (force action on a unit charge) and E is the potential at a point distant r centimeters from the point where the inducing charge is located. In the general case g is some function of r. To illustrate, if an electric charge of q units is concentrated at a point P, the field intensity of another point r centimeters distant from P is, by the second concept, $g = q/r^2$. Therefore the electric potential at the point r centimeters distant from P is

$$E = \int_r^\infty \left(\frac{q}{r^2}\, dr\right) = \frac{q}{r}$$

Thus the seventh concept, the concept of electric potential has been derived. The fact that the field intensity g usually is some function of the distance r adds complications in the practical applications of the concept.

The eighth concept grows out of the previous one. It is more important practically, because ordinarily one is interested not in absolute potential (elevation above the absolute zero of elevation) but in difference of potential (difference in elevation). By way of illustration, the voltage between 2 points, distant r_1 and r_2 centimeters, respectively, from the point P at which is concentrated a charge of q units is

Figure 4. Sketch showing the resultant dielectric field between the 2 conductors of a single-phase circuit



$$V = \int_{r_1}^{r_2} g\, dr$$

Before integrating this expression, substitute for g its value in terms of q and r as indicated in the previous illustration.

If this equation be differentiated, 2 useful relations result:

$$dV = g\,dr \quad \text{and} \quad g = \frac{dV}{dr}$$

If the field intensity along a path is uniform, then g will be a constant and not dependent on the distance r. The voltage between 2 points on this path, located l centimeters apart is

$$V = \int_0^l g\,dr = gl$$

But from the sixth concept, $g = D/K$; therefore,

$$V = \frac{Dl}{K} = \frac{ADl}{AK}$$

where A equals the cross section of the flux path in square centimeters. But $AD = \Psi$ and so

$$V = \Psi \frac{l}{AK} = \Psi S$$

where

$$S = \frac{l}{KA}$$

It will be noted from these algebraic formulations that out of this concept grows the important relation, $V = \Psi S$, where V has the significance of voltage or difference in elevation or pressure, Ψ the significance of flux and S that of resistance. (S sometimes is called elastance and is measured in units known as darafs.) Thus this relation is similar to $E = IR$ in the electric circuit and to $\mathfrak{F} = \Phi\mathfrak{R}$ in the magnetic circuit.

Also the reader will see that elastance $S = l/KA$ is similar to reluctance in the magnetic circuit, where $\mathfrak{R} = l/\mu A$, and to resistance in the electric circuit, where $R = l/\rho A$ (the factor ρ is the reciprocal of resistivity).

Another idea of importance is that the term g is equal to dV/dR, that is, to the rate of change of voltage with distance, or to the so-called potential gradient. The quantity g, therefore, can be measured in volts per centimeter, volts per inch, or other suitable units. Also since $g = D/K$ it is apparent that g varies directly with the dielectric flux density. This idea is of great value to the engineer in designing insulation because points at which the flux density is high are the danger points as far as insulation breakdown is concerned.

The ninth concept is well known, but the relations between S and C may not be so well remembered. From the relation $q = VC$ a capacitor seems to be a sort of electrical tank into which electrons can be pushed and the more electrons that are crowded into the tank, the greater the pressure V will be. From another point of view the relation $C = 1/4\pi S$ indicates that from the dielectric circuit standpoint capacitance is akin to permeance, or the reciprocal of reluctance in the magnetic circuit.

The first 2 "boxes" contain about all that is needed to solve most of the problems in electrostatics. The difficulty comes in the application of this basic knowledge. Ordinarily 2 somewhat different procedures are followed, either separately or in combination, in the solution of such problems. Rather arbitrarily, and with no offense intended to either group, for the present one method may be called the method of the physicist and the other the method of the engineer. One method consists of placing imaginary charges at desired points and computing their effects. The other method accomplishes the same end by visualizing of lines of flux and determining the desired results from formulas applicable to this visualization.

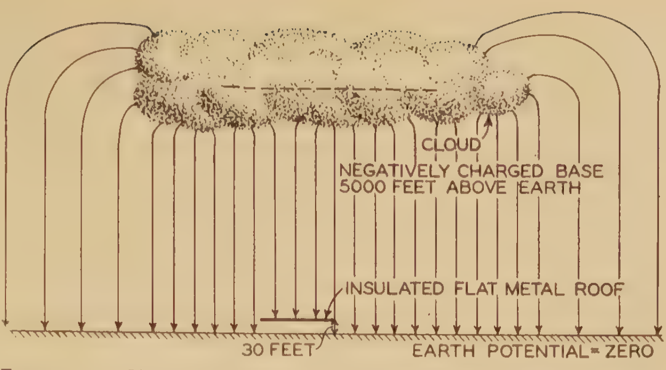


Figure 5. Sketch showing how an insulated object close to earth may have a potential introduced in it by a charged cloud

In the twin boxes headed "Physicist" and "Engineer" a few typical examples have been worked out illustrating the application of the 2 procedures. The reader will notice that under the procedure headed "Physicist" a charge is assumed on the capacitor plate or wire, the gradient is then determined at some point, as at x distance, and then the gradient is integrated to obtain the voltage between plates or wires, the capacitance being later determined if desired by the $q = VC$ relation. Under the other procedure the elastance S is determined from the physical dimensions and then the capacitance from the relation $C = 1/4\pi S$. As elastance depends only on physical dimensions and quality of insulation, this method, as far as technique is concerned, is similar to the determination of resistance in the electric circuit and reluctance in the magnetic circuit. This is of practical importance where the design involves forms not reducible to simple geometric figures and where, therefore, mapping of the field is necessary. In general, with this procedure the engineer may use the same methods for solving dielectric-circuit problems that he uses in solving electric- and magnetic-circuit problems. This does not condemn the first procedure, however, for these procedures are but tools in the engineer's tool kit. No one would think much of a man's ability as a carpenter if he used the same saw to rip rough work and to cut off pieces of finishing lumber. Each tool has its advantages and the one used should be the one that will do the job most efficiently.

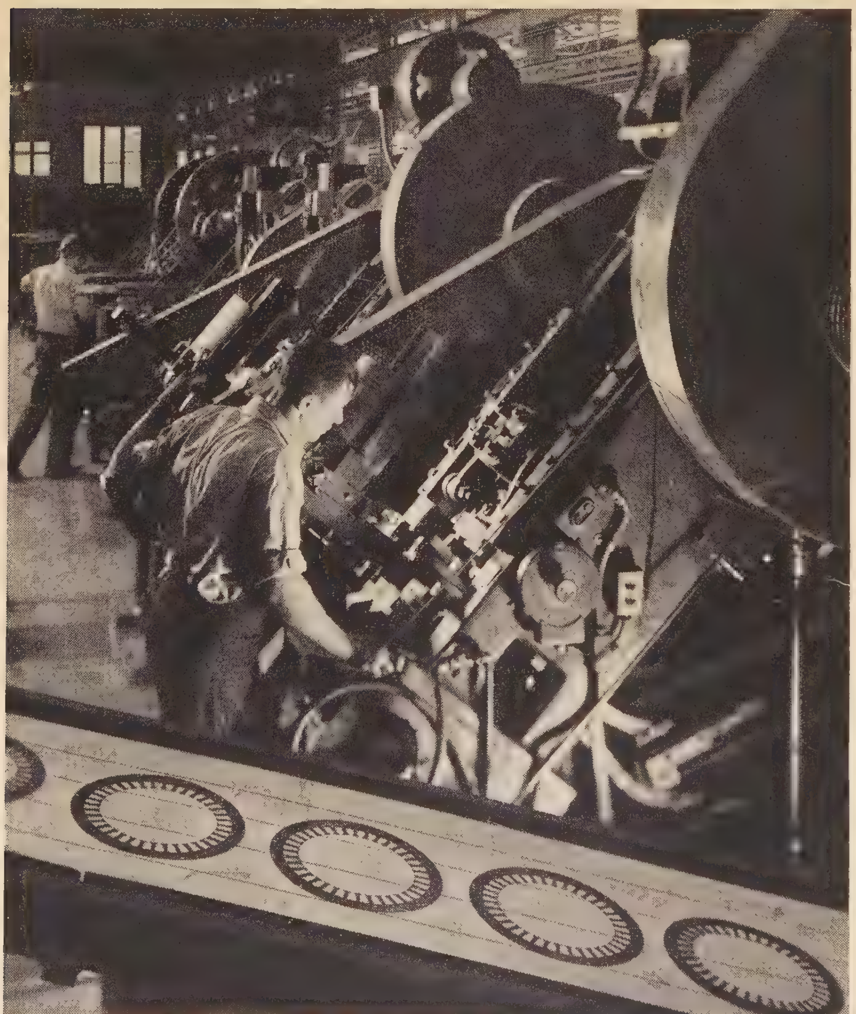
In the third example, using the second procedure, an equation for the absolute potential E_A of wire A has been set up in terms of fluxes and elastances. In this case there were 2 energized wires and therefore wire A is in 2 component fields: its own field and that set up by wire B. There are 2 terms in the equation, therefore. Had it been a 3-phase circuit with 3 wires there would have been 3 terms, and so on. In this example, as in many problems in mechanics, the computer has the choice of using either

the components or the resultant of the components. The component fields, that is the field set up by each wire acting separately are shown in figure 3, the resultant force at a given point P being shown together with the 2 components at this point. The resultant field between the 2 wires is shown in figure 4. It is quite apparent that the component fields, because of their simple geometry, are much easier to work with than the resultant field. In the example under discussion each term in the absolute-potential equation represents the effect of a component field.

As another example of the second procedure, assume that the potential to ground induced by a charged cloud as in figure 5 on a perfectly insulated metal roof must be determined. If the field under the cloud is reasonably uniform the potential of the roof can be estimated with some accuracy, because here, as with other series circuits, the potential of the roof has the same ratio to the potential of the cloud as the elastance from the roof to the earth has to the elastance from the cloud to the earth. Assuming the earth's surface to be at zero potential (which is not often correct) the roof potential is 30/5,000 of the potential of the cloud. In practice the potential never would be indicated by this calculation, because the roof would not be perfectly insulated from the ground.

Finally, there is one other idea that may be of some use in clarifying the reader's thinking relative to the dielectric circuits involved in transmission lines. Assume that water must be circulated through a large block of concrete, such as the Boulder Dam, for example. How could it be done? Someone might suggest that pipes or ducts should be placed in the concrete while the concrete was being poured. Quite true. Pumps then could be connected to these pipes and the water could be circulated without any difficulty except that offered by the resistance of the pipes to the flow of water. Now electrons travel through the air about as freely as water travels through concrete. If electrons are to be transmitted through the air, suitable holes or tunnels must be provided for them to travel in, just as holes through the concrete are provided to permit the circulation of water. When a line gang is sent out to build transmission lines, then, they really are being sent out to string electron holes through the air.

If too much pressure is put on the water in the hole in the concrete, radial cracks or failure of the concrete around the circumference of the hole might be expected. Similarly, if too much voltage (pressure) is placed on the electrons traveling in the holes in the air (wires), failure of the air around the circumference of the hole (wire) will result and the phenomenon known as corona will appear.



Recently placed in operation at the East Pittsburgh (Pa.) works of the Westinghouse Electric & Manufacturing Company, the battery of automatic inclined punch presses shown at the left is part of a new straight-line-production system of manufacturing a-c motors of the standard industrial type, ranging in size from 1 to 50 horsepower. Rotor and stator laminations fall from these presses upon endless belts, which convey them to other conveyors and thence to automatic assembly jigs. Although the new "motor aisle" is intended to specialize in the production of "standard" motors it is said to have facilities for turning out special items without impeding regular production

Scientific Research Applied to the Telephone Transmitter and Receiver

By EDWIN H. COLPITTS
FELLOW AIEE

Improvements in the transmitter and receiver, instruments basic to the telephone art, continually have led to a higher grade of service and further economies. Research work has made possible predetermination of performance by calculation; the effect of studies of speech sounds, hearing, materials, and testing methods on the development of instruments giving high quality for conversation is shown by this article, which is based on one of three Iwadare lectures* delivered in 1937.

LET US recall a scene at the Centennial Exhibition in Philadelphia in 1876. Across a room had been strung wires connecting crude instruments, at one end of the room a transmitter and at the other end of the room a receiver. Dom Pedro, Emperor of Brazil, takes up the receiver and listens while Alexander Graham Bell speaks into the transmitter. The Emperor, astonished at hearing Mr. Bell's voice in the receiver, exclaims in amazement, "My God, it talks."

When at the same place, Sir William Thomson (later Lord Kelvin) took up the receiver and listened to Mr. Bell, the words of this distinguished scientist were, "It does speak," and continuing, "it is the most wonderful thing I have seen in America."

Sixty years have passed and, as a result of continued effort, the use of the telephone has become such an everyday matter that even the ability to talk from one continent to another scarcely excites comment or wonder. It is not surprising that, to the layman, the element of distance seems the most striking factor in the technical development of the telephone art. As a matter of fact, while the conquest of distance has involved much scientific effort, and very ingenious and highly developed methods for the transmission of speech currents, the magic of the telephone still resides in the instruments which provide for the conversion of mechanical energy, namely speech sounds of highly complex wave form, into electrical currents of corresponding wave form, and the reverse process of converting these electrical currents into speech sounds. These instruments, the transmitter and the receiver, are basic to the whole telephone art. As they have been improved by development and design, it has become possible not only to render a higher grade of service but to effect economies in other portions of the plant. For example, the very extensive use of fine-gauge cables was, to a large extent, made possible by the development of more efficient transmitters and receivers. Further perfecting of these instruments promises additional improvements in service and some further economies.

Telephony, restricting the term to ordinary 2-way talking between individuals, involves an element not present in any other service. It does not greatly concern one customer of an electric light or power company whether another customer chooses to use inadequate or inefficient or poorly located lamps or other equipment. That is, each user of the service is, under any ordinary conditions, independent of all other users. In the case of telephony, however, the problem is entirely different; for one user of the telephone is greatly concerned with not only the apparatus furnished to any one with whom he has occasion to talk but also with other factors affecting the use of this apparatus, such as the amount of noise in the room where the apparatus is located, the user's habits of speech, and whether his ability to hear is normal. Telephone instrumentalities must therefore be so designed and the plant so engineered as to meet reasonably wide variations from what may be termed normal conditions, and ratings of performance should be similarly established.

No single factor is more important to a sound development of this art than the subscriber apparatus. The research program basic to the development and design of transmission instruments has itself been a matter of development as a better understanding of the problems unfolded and as the need for research in this or that direction became apparent. The research problem basic to the development and design of transmission instruments may be described as having the following very broad scope: an understanding of their physical operation viewed as electromechanical structures; an understanding of speech mechanism and an accurate physical definition of speech air waves; an understanding of the hearing processes and a determination of how hearing is affected by factors present in telephony. Also, the research program may be said to have included research upon certain materials, the results of which have an important bearing either upon an understanding of the operation of these instruments or upon their practical design. In addition to the development of many methods of measurement and testing applicable to laboratory research and development, of very

* Essential substance of a lecture delivered in the spring of 1937 in Japan under the sponsorship of the Iwadare Foundation. This foundation was established in the Denki-Gakkwai (Institution of Electrical Engineers of Japan) for the following purposes: (1) to send one or two Japanese electrical engineers to the United States each year to study for about one year, and (2) to invite distinguished electrical engineers from the United States to deliver several lectures in Japan once or twice a year. The Japanese society asked the assistance of the AIEE in the guidance of the engineers sent to the United States for study, and also in the selection of distinguished electrical engineers to lecture in Japan. The AIEE board of directors authorized a committee for this purpose in 1931.

EDWIN H. COLPITTS retired early in 1937 as a vice-president of the Bell Telephone Laboratories, Inc., New York, N. Y., after having been engaged in telephone work since the beginning of the century. He has been granted many patents, and has written numerous technical papers. Recently he was awarded the Japanese Fourth Order of Merit of the Sacred Treasure in recognition of his promotion of electrical engineering in Japan.

great importance has been a development of the testing methods which permit of a better final evaluation of the developments based upon the results of this activity.

Instruments as Electromechanical Structures

The telephone transmitter itself is a complex mechanical and electrical structure. Its general method of operation can be described qualitatively in relatively simple terms, but the operation of few structures is more difficult to define in definite quantitative terms and relationships. For example, there are acoustical problems such as those involved in the air connection between the lips of the speaker and the diaphragm of the instrument. This air connection may involve a short column of air as in those instruments which have a telephone mouthpiece. Connection between the column of air and the working parts of the transmitter may be partially closed by a perforated section. When the operation of the instrument itself is considered, there is involved the mechanical vibration of the diaphragm as it operates on the carbon, and further, the whole question of electric conduction in the small mass of granular carbon itself.

In the receiver which converts telephonic currents into speech sounds, there are very similar acoustical, mechanical, and electrical problems with the exception, of course, of the mechanical and electrical problems introduced by the carbon of the transmitter.

A large amount of research work has been carried on relating broadly to the transmitter and the receiver as electro-mechanical physical structures. The theory of these devices as vibrating systems has been developed so that their over-all performance can be related to the various structural features. Consequently, development and design engineers are now enabled to predetermine by calculation how certain modifications in structure will affect the physical performance of the instrument. In other words, the design process has become very much less "cut and try."

Research has been undertaken and substantial progress has been made on a study of microphonic action in carbon.

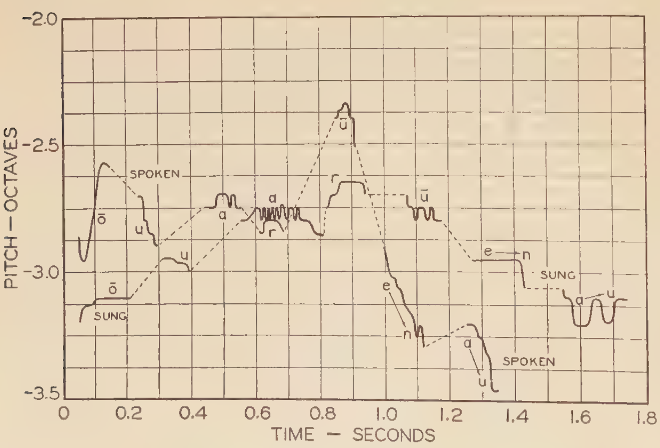


Figure 1. Melodic curves showing the variation of pitch with time as the sentence "Joe took father's shoe bench out" is spoken and sung

In order to develop a complete theory of the operation of the transmitter, it is necessary to understand fully what takes place between each carbon granule in the carbon chamber.

Speech Sounds

The source of any voiced sound is in the larynx. On both sides of this larynx there are 2 muscular ledges called the vocal cords. During breathing these ledges are widely separated, but when a voiced sound is produced, they come close together, forming a long narrow slit. As they come close together, the air passing through the resulting slit is set into vibration producing a sound. It has been generally supposed that the pitch of the tone thus produced was determined by the natural frequency of vibration of the 2 vocal cords, and that by changing the tension of these cords, the pitch of the tone can be raised or lowered at will. The studies revealed that the natural pitch of these cords while a tone is being produced is considerably below that of the pitch of the tone. It is true that the pitch of the tone produced is affected, somewhat, by the elasticity of the vocal cords, but it is principally controlled by the size of the air opening between them. The little plug of air between the 2 vocal cords vibrates through a very much larger amplitude than the amplitude of the cords themselves and is the real source of the sound. The mass of this small plug is controlled by the size of the opening and by the elastic forces pushing it to and fro—namely, the air pressures on either side of it. It is evident that these oscillating pressures will be influenced by the size and shape of the trachea leading into the lungs on one side and by the size and shape of the tongue, mouth, and nasal cavities on the other. The mechanical action involved is analogous to the electrical action in a vacuum-tube oscillator. The sound which is generated at the vocal cords is modified as it passes through the throat, mouth, and nasal passages. The real character of the sound which enables identification of words is wholly dependent upon the manner in which this cord tone is modified by the changing sizes, shapes, and characters of these passages and the outlet to the outside air.

After the various speech sounds leave the mouth, they are transmitted to the ear of the listener by means of air vibration. As an example of the type of disturbance created in the air, consider the sentence, "Joe took father's shoe bench out." This silly-sounding sentence is chosen because it is used for making tests on the efficiency of telephone systems. The sentence, together with its mate, "She was waiting at my lawn," contains all the fundamental sounds in the English language that contribute appreciably toward the loudness of speech. As the sound wave produced by speaking this sentence travels along, each particle of air over which it passes executes a vibration through its original or undisturbed position. The successive positions occupied by the particle as it moves in the complicated series of vibrations corresponding to a spoken sound can be visualized in laboratory investigations from oscillographic records of the corresponding telephone currents.

Each successive particle of air along the line in which the sound is traveling executes a similar complicated series of vibrations but any particular oscillation is performed at a later instant by the particle which is farther away from the source of the sound. The disturbance in the air which represents a spoken sound may then be pictured either, as was first described, in terms of the successive positions of a single particle or in terms of the displacements at any instant of each of the particles along the line of travel of the sound wave. For example, for the sentence "Joe took father's shoe bench out," the disturbance carrying the sound *j* in the word "Joe" is about 1,500 feet from the mouth by the time the sentence is finished.

If an analysis is made of the wave when the sentence "Joe took father's shoe bench out" is spoken, the variations in pitch of the speech sounds can be determined from the vibration rate. Such an analysis is shown in figure 1. The variations in pitch are represented on the vertical axis, zero being taken at 1,000 cycles per second. The duration of the sounds in fractions of a second is represented on the horizontal axis. It may be seen that the pitch rises and falls as the various sounds are spoken. This representation of the pitch variation is called the fundamental melodic stream. It is the melody in the same sense as this term is used in music, although it is evident that the pitch changes do not take place in musical intervals as would be the case if the sentence were sung.

To show the contrast, a graph was made when the sentence was intoned on the musical intervals *do, re, mi, fa, mi, re, do*. An analysis of the graph gave the result shown in figure 1. In the case of the sung sentence the pitch changes are in definite intervals on the musical scale, while for the spoken sentence the pitch varies irregularly, depending upon the emphasis given. The pitch of the fricative and stop consonants is ignored in the musical score, and since these consonants form no part of the music, they are generally slid over, making it difficult for a listener to understand the meaning of the words. A singer's principal aim is to produce beautiful vowel quality and to manipulate the melodic stream so as to produce emotional effects. To do this, it is necessary in singing to lengthen the vowels and to shorten and give less emphasis to the stop and fricative consonants. It is for this reason that it is more difficult to understand song than speech.

There are 2 secondary melodic streams of speech represented by the second and third curves from the bottom of figure 2, which are due to the resonances imposed upon the speech sound by the throat and mouth cavities. The numbers on these curves give the number of the harmonic which is reinforced. These 2 secondary melodic streams are not sensed as changes in pitch, but rather as changes in the vowel quality. Then there is a fourth stream, or, it would probably be better to say, a fourth series of interrupted sounds which are very high in pitch and are the sounds which enable us to identify the fricative consonants. The secondary melodic streams produced while speaking the same sentence are approximately the same for different persons, even for a man and a woman, while the fundamental melodic stream is usually quite different. This latter stream is not used in identifying words, but it is

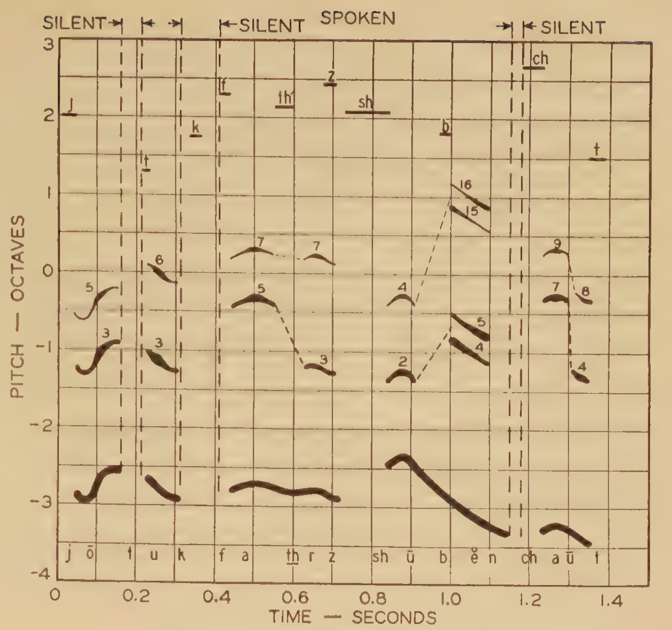


Figure 2. Melodic curves showing the variation of pitch with time as the sentence "Joe took father's shoe bench out" is intoned on the musical intervals do, re, mi, fa, mi, re, do. The pitch changes in regular intervals rather than in irregular intervals as shown in figure 1

used sometimes to give different meanings to the same words.

As one listens to this sentence he hears the variations in loudness as well as in pitch. Loudness is related to the amplitudes and frequencies of the components of the tone, but this relationship is very complicated. It is dependent upon the action of the ear, including the nerve mechanism carrying the message to the brain. This relationship has been under study for several years so that it is now possible to calculate from physical measurements the loudness for a typical ear and also to devise instruments for measuring approximately the loudness of any sound. The result of using such a device for recording the variations of loudness in the spoken sentence which has been discussed is shown in figure 3. For comparison, the variations in pitch are also shown in this figure.

It is not possible here to describe the devices by which the energies and frequencies involved in speech are measured accurately, but the results of this research work are interesting. When this sentence is spoken fairly rapidly, it will contain about 200 ergs of energy. About 500,000,000 ergs of energy pass through the filament of an ordinary incandescent lamp each second. This shows that the acoustic energy in this sentence is very small. An examination of the wave produced by this sentence shows that the vowels contain considerably more energy than the consonants. Exact measurements have indicated that in ordinary conversation the ratio of the intensity of the faintest speech sound, which is *th* as in "thin," to the loudest sound, which is *aw* as in "awl," is about one to 500. The actual power used in producing the various sounds depends, of course, upon the speaker and the emphasis with which he pronounces the sound. The

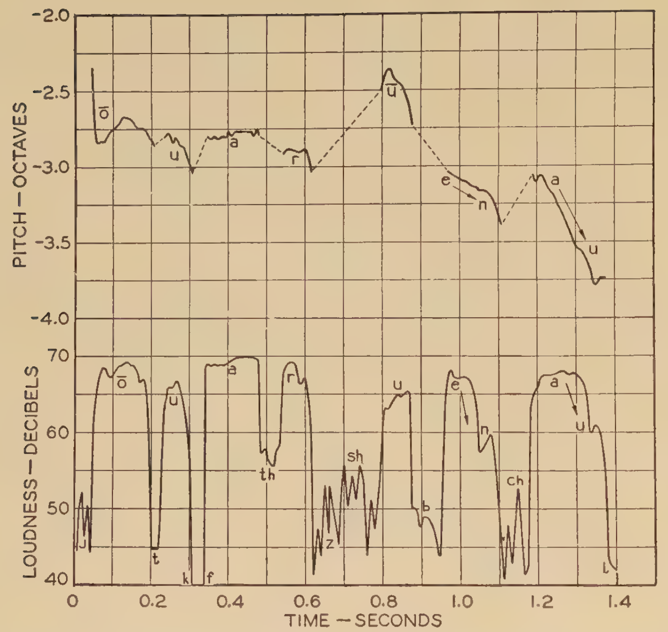


Figure 3. Graph of the loudness of the various sound elements when the sentence "Joe took father's shoe bench out" is spoken

power in an accented syllable is 3 or 4 times that in a similar unaccented syllable. Measurements upon voices during a conversation have indicated that the average power in the speech produced is 10 microwatts. Some speak with more and others with less than this power. Tests on a sample group show that 7 per cent speak with less than one sixteenth the average power, 18 per cent use powers lying between one quarter and one half the average, and 4 per cent between 4 and 8 times the average. No speakers were found to use more than 8 times the average for conversational purposes.

As a conversation proceeds, the speech power varies from zero during the silent intervals to peak values which frequently are 100 times the average power. Examination of one-eighth-second-intervals throughout a typical conversation shows that for 17 per cent of them the peak power lies between 8 to 16 times the average over a long interval. It is found that the most frequently occurring value of the peak power is about 10 times the average.

Although a typical voice of a man and a typical voice of a woman are alike in that they use the same average power and variations of power from this average, they are different in other respects. It is well known that the pitch of the voice of a woman is about one octave higher than that of a man. It was not known, however, until laboratory experiments revealed it, that the intensity of the components having vibration rates above 3,000 cycles per second was definitely greater for voices from women than from men. For some reason which is not very evident, women use higher pitch sounds for producing the fricative consonants, and this results in greater power in the regions of higher pitch. Every one who is familiar with transmission systems knows well that these high-frequency components are nearly always eliminated. While these sounds are not of controlling importance in properly understanding speech, it is evident that the women's voices are somewhat handicapped as compared with men in systems which eliminate them.

Hearing

Paralleling research on speech sounds, hearing has been investigated. Broadly speaking, the aim has been to arrive at an accurate physical description and a measure of the mechanical operation of human ears in such terms that they may be related directly to the electrical and acoustical instruments. The keenness of the sound-discriminating sense has been measured, and the smallest distortion which the mind can perceive, and how it reacts to somewhat larger distortions, has been determined. This information is utilized in determining a reasonable basis of design both for separate instruments and for transmission systems as a whole, to give a proper balance between cost and performance.

One of the first steps was to determine in a quantitative way the performance of ears as machines. It was obviously important to know how faint a sound the ear can hear, and also how loud a sound the ear can tolerate. With the advent of the vacuum tube, it was possible to develop methods of accurately measuring the intensity of faint sounds and of readily producing such sounds. Figure 4 gives the results of measurements made to determine the limits of hearing. This graph is called the auditory sensation area. The lower solid curve represents the minimum sound that an average young person can hear. The abscissa gives the frequency of the pure tone, and the ordinate the sound pressure in dynes per square centimeter. The top solid curve represents the maximum intensity of sound that the ear is capable of handling. This curve was determined by noting that intensity which produced a feeling sensation. Intensities slightly higher than this result in pain and in some instances serious injury to the ear. The dotted lines on either side complete the enclosure and represent the upper and lower limits of pitch that can be heard. From this figure, the upper or lower limit of pitch obviously is greatly dependent upon the intensity at which the sound is produced. It may be seen that near the middle range of frequencies, the pressure range is one million to one. The pitch range of pure tones is from about 16 to 25,000 cycles per second.

These results are for young adults, and it may be of interest to note that as one becomes older the hearing acuity, at the higher frequencies particularly, becomes less. In table I are shown some measurements to determine what the effect of age would be upon the hearing acuity; these are average values obtained from measurements on a large number of persons.

Another important measurement of average hearing is that concerned with minimum perceptible differences in pitch and in intensity. Careful measurements on large groups of people have given reliable data. Near the threshold changes in intensity of about 4 decibels are necessary to be perceptible, while at fairly high intensities about $^1/_4$ decibel is all that is necessary for the change to be perceived. Minimum perceptible differences in pitch

vary from about 0.0025 octave to 0.19 octave, depending on the frequency and the intensity. The results of this line of investigation have an important bearing on the physiological theory of hearing, and another important result has been the development of methods of determining the degree of impairment of hearing.

In telephony we are, of course, not directly concerned with simple sounds, but with the highly complex sounds of speech, and these are on actual telephone circuits generally associated with extraneous sounds which may be grouped under the broad term of noise. Further, telephone instruments are not perfect, and could be made to approach perfection only at a great expense. In order to arrive at a quantitative understanding of the importance of departures from perfection in telephone transmission elements and conditions of use, the general procedure in very general terms has been as follows: Transmission systems so nearly perfect that even the keenest ear could not find a flaw in their transmission performance are set up, and then measured imperfections or variations are introduced.

By this general process, the effect of noise of chosen intensities either as noise present in the telephone receiver or as noise in the room was determined. Similarly, the effect of a line or other characteristic such that voice frequencies above a certain value or below a certain value were not transmitted, was determined. The effect of introducing a highly resonant element or of a nonlinear element was studied. The range in loudness of speech necessary for best reception was likewise measured.

As noise became recognized as a very real factor, a standard basis for noise measurements was established. Consequently it is now possible to measure noise on a telephone circuit or in a room, and to state the result in terms of a standard unit.

Materials

In the practical design of modern telephone instruments we owe a large debt to the chemist and the metallurgist. Modern molding materials and processes are utilized in order to secure forms of apparatus satisfactory from the standpoint of appearance and of mechanical strength. The newer types of permanent magnet steel provide possibilities of light-weight and very efficient magnetic structures.

It is a most striking circumstance that commercial telephony is dependent upon the performance of a small mass of carbon granules in the transmitter. No single material entering into the construction of telephone apparatus has therefore greater importance. In America at least, transmitter carbons are largely derived from a certain specially selected anthracite coal. In its natural state, this coal exhibits none of the characteristics required for its use in a transmitter. These characteristics or properties are secured by heat treatment. These heat-treatment processes were for many years the result of empirical development and were not well understood nor, as is now recognized, adequately controlled. This resulted in a product of uncertain quality. An important task of the Bell Laboratories was therefore to study each step in the process of producing carbon and to develop a process definitely specified at each step, which would be capable of giving the desired uniform quality. The results so far obtained have had very important reactions upon transmitter performance. The Laboratories have also set themselves the more elementary task of understanding the fundamental properties of carbon contacts. One important element of this research is to determine the causes of resistance changes produced when the compressive force on a mass of carbon granules is changed. It is too early to report results from this research, but it seems clear that granular carbon will be an important element in the design of transmitters for many years to come, and we should seek to obtain complete fundamental knowledge of its operation.

Table I. Decibel Loss in Hearing With Age

Frequency	60 to 1,024 Cycles	2,048 Cycles	4,096 Cycles	8,192 Cycles
Ages 20–29 (96 ears)	0	0	6	6
Ages 30–39 (162 ears)	0	0	16	11
Ages 40–49 (84 ears)	0	2	18	16
Ages 50–59 (28 ears)	0	5	30	32

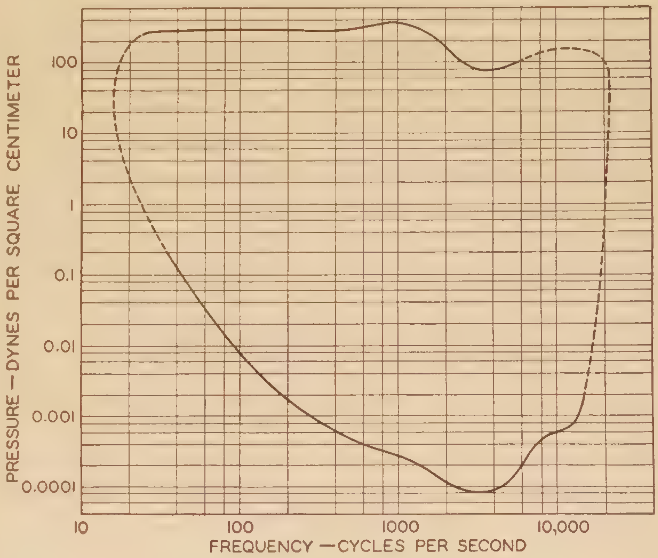


Figure 4. Auditory sensation area for the typical ear of a young adult

Testing Methods

Broadly speaking, methods of testing have been developed, first, to enable the development and design engineer to determine quantitatively the various performance factors of the apparatus under development, and second, to determine how well the apparatus which has been developed performs under service conditions. In the Bell Laboratories, methods have been developed during the last 20 years for measuring the physical constants of the apparatus involved so that this apparatus may be an-

alyzed as electromechanical structures. Further, in the design of telephone transmission apparatus we are concerned with a power transmission system in which the design engineer has no control over the power source, the human voice, nor over the receiving agency, the human ear. His control is limited to the conveyance of power from speaker to listener. In the Laboratories, therefore, we have recognized that it is necessary, at least with our present knowledge, to supplement physical measurements by measurements involving speech sounds and the human ear. Some years ago, these tests consisted of comparisons between different instruments or transmission elements made by the process of talking first over a circuit containing, for example, one instrument, and then over the same circuit containing a different instrument. Dependence was placed wholly upon the listener's skill to detect differences in volume, quality, and intelligibility. It was recognized that this method of testing left much to be desired. Owing to the limitations of the human ear, small volume differences could not be detected, but even more important, this simple test furnished no very accurate measure of speech distortion affecting intelligibility, and obviously no definite information as to the relation between volume, various types of distortion, and over-all effectiveness.

Doctor George A. Campbell, in 1910, proposed a method of testing which has been highly developed in the Laboratories. This method, termed "articulation testing," measures the relation between the reproduced and impressed sounds from the standpoint of effects on intelligibility of different kinds of distortion. This method has been described in several publications. Briefly, in this method, lists of syllables chosen at random and usually meaningless monosyllables are called over the circuits to be rated, and the percentage of syllables correctly understood gives a measure of the circuit performance. Further, the method has been extended to give quantitative measures in terms of the recognizability of reproduced speech sounds, of the effects of loudness of these sounds, and of the noise which may be present.

While various physical tests and the articulation test method are exceedingly useful tools in the hands of the research and development engineer, they do not give a direct measure of the transmission service performance of a circuit in terms of the ability of the user to carry on a conversation under actual commercial conditions. This ability of the user to carry on what may be termed a successful telephone conversation depends not only upon the performance of the telephone instruments and circuits but also, to a substantial extent, upon the users' own performances—the subject material of conversation, how they talk into the transmitters, and how they hold the receivers—and upon the room noise conditions. In other words, there are a number of factors random in nature which, while beyond the control of those who design and engineer the telephone plant, must be taken account of in rating the service performance.

Much thought and effort have been given to the problem of how best to determine transmission service performance. Very briefly stated, we have been led to the following steps: In order to take suitably weighted account of all the factors involved, service performance ratings should be based on service results, that is, transmission service performance should be measured by the success which users of the telephone circuit have in carrying on conversations over the circuit. With the various factors in mind, we have fixed upon what we have termed "effective transmission" ratings for transmission plant design. These ratings are based on a determination of the *repetition rate* in normal telephone conversations.

As the effect of a change in a circuit depends upon its initial characteristics, it is necessary in order to be able to compare numerical results to have a basic circuit for reference. By suitable choice of basic circuit, it is possible to express the effects of changes in any one transmission characteristic in terms of the attenuation of the trunk. For example, the effect of changes in sidetone level in the subscriber's set can be expressed as so many decibels change in trunk attenuation.

Association of Transmitter and Receiver

In order to furnish a convenient 2-way talking circuit over a single pair of wires, the transmitter and the receiver at each end of the circuit must be continuously associated in the circuit. This has been accomplished by various circuit arrangements since the early days of the telephone, and as every user of the telephone knows, leads to the condition that when speaking into the transmitter one hears his own voice in the receiver. Local speech so heard is designated as sidetone. The Laboratories have carried on research in order to determine the effect of sidetone on the over-all efficiency of the circuit. Sidetone above a certain volume has been found to decrease the conversational efficiency of the circuit. Parallel with the study of the effects of sidetone, research has been carried on on methods which could be applied to limit sidetone in amount to more nearly its optimum value. This has led to the development of what are known as anti-sidetone circuits, which do not eliminate sidetone but reduce it to an amount which is more nearly that found to be desirable.

An important step in the association of the transmitter and the receiver is represented by the handset which provides a rigid mechanical connection between the 2 units. This rigid mechanical connection introduces mechanical coupling between the receiver and the transmitter, which had to be given very serious consideration in order to avoid speech distortion.

Trends in Instrument Development

I have broadly indicated fields of research which underlie the development and design of the telephone transmitter and receiver. It will now be of interest to note what application is likely to be made of the results of what has amounted to an enormous total of scientific effort. In this connection, it may be well again to emphasize that station apparatus is intimately associated with the user, and has therefore to be designed to fit him, his habits of using the telephone, and the conditions attending such

use. The handset has to be designed to fit his head, the holes in the dial to fit the size of his finger, the bell to be loud enough, and so on. Our effective transmission rating system has been set up in an attempt to rate the performance of the telephone when employed by the customer in

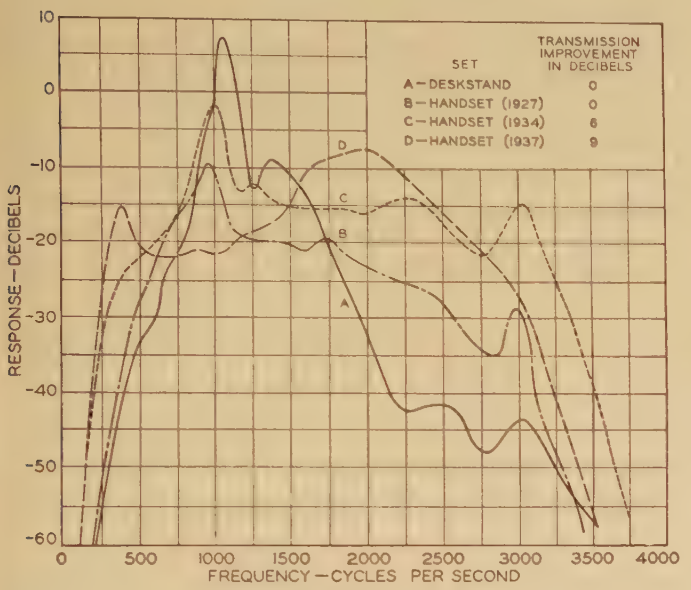


Figure 5. Comparison of the response-frequency characteristics of telephone instruments

the way he wants to use it, under the conditions surrounding him. For this reason, this method of rating has been found particularly valuable in the development work on instruments.

Because of the wide range of customer usage and conditions, a number of factors have to be taken into account in the design of the apparatus. Also, because this apparatus is located on the customer's premises, where it is relatively inaccessible to the telephone personnel, it must be capable of standing up without undue trouble under this wide range of usage and conditions. To strike a proper balance in meeting all these factors requires an intimate knowledge of the field conditions as well as of the development and manufacturing possibilities. A continuing close contact with field experience is employed to modify the designs toward securing the proper balance to meet these factors.

In order to indicate more clearly the present trends in design, I shall refer briefly to the earlier art. In the early development of transmitters and receivers, the matter of getting efficiency was of primary importance since this could be evaluated directly in terms of the amount of copper required in the connecting line. The early transmitters, which were of the same construction as the receiver, depended on the generator action of a diaphragm and coil and developed sufficient power to be heard over only a few miles of heavy-gauge wire. Some amplification was necessary before telephone communication could begin to assume the proportions of a widespread service. This amplification was obtained at a reasonable cost in the carbon-contact transmitter. Transmitters of this type are in the order of 60 decibels more efficient as transducers of acoustic to electric energy than the earlier type.

Both the transmitter and the receiver operate by means of diaphragms which have natural periods of vibration. These resonances and the resonances of the air spaces on each side of the diaphragm were used to obtain as efficient a transfer of energy as possible. In the early design, a great deal of attention was also given to locating these resonances at the portion of the frequency range where they would tend to increase the intelligibility of the reproduced sound. As a result, both instruments were made very efficient in the region of 1,000 cycles, which lies within the range where the ear and the sensation of loudness are most sensitive.

It was recognized that these resonances caused undesirable distortion, but under the conditions the resulting increase in efficiency more than compensated for this disadvantage. As time went on, the diaphragm resonances came to be looked upon as practically inherent in commercial transmitters and receivers, because no way was known of eliminating them without making a very material sacrifice in the efficiency of the instrument.

About 20 years ago, the development of the vacuum-tube amplifier and the high-quality condenser transmitter made it possible to demonstrate and measure quantitatively the advantages of reducing distortion. These high-quality instruments, the improvement in measuring technique, and the development of improved methods of designing vibratory systems offered the promise of providing instruments in which the resonance effect could be reduced without unduly affecting efficiency.

The first commercial instrument for station use, which demonstrated the possibility of carrying out this promise, was the transmitter employed in the handset first supplied by the Bell System in 1927. This transmitter had to meet the requirement of giving the same transmission service as transmitters of the deskstand type, and at the same time meet the very exacting requirements imposed by the handset to make it free from howling and capable of performing over a wide range of positions. The diaphragm resonance was damped to a large extent by the use of paper rings and, by lightening the structure, the point of maximum response was moved up in frequency so that it no longer coincided with the peak of the receiver. The effect of this was not only to broaden the response characteristic and improve intelligibility, but also to reduce the gain in the local howling circuit which is, of course, a maximum when both transmitter and receiver have their greatest efficiency at the same frequency. The same separation of peaks resulted in the received speech being less loud, but in spite of this the over-all performance was equivalent to that of the best deskstand type of instrument then available.

With this accomplishment, further work was directed toward maintaining the lower distortion and increasing the efficiency. The transmitter introduced in 1934 represented a marked improvement along this line. This instrument still further broadens the transmitted frequency range and is used with about the same efficiency in deskstands, handsets, wall sets, and coin-collect sets.

A new type of handset is being introduced in the Bell System in 1937 which, in addition to having a more pleasing and simplified design, will incorporate the new transmitter mounted in such a way as to make fullest use of its ability to transmit efficiently over a wide-frequency band.

During this evolution of the transmitter, the knowledge which had been gained as to the importance of transmitting different widths of frequency band over commercial telephone circuits led to the establishment of the range from 250 to 2,750 cycles for designs of new circuits. It was not the intention in the establishment of this range that circuits should not do better than this where it is possible without materially increasing cost, but that all circuits should be at least as good as this. The establishment of this frequency range took into account a number of factors of which a very important one is that the over-all utilization of this range from the sound entering the transmitter to the sound output of the receiver provides a grade of transmission which is highly satisfactory for the reproduction of conversational material.

The establishment of this frequency range played a part not only in the design of circuits, but also in guiding the evolution of the transmitter and receiver. The transmitter last referred to meets this requirement very well. In fact, its efficiency is fairly uniform for a frequency range extending beyond 4,000 cycles.

The next step in the process was to improve the performance of the receiver. A pronounced resonance at 1,000 cycles was no longer necessary since means had been found to improve the efficiency of instruments in other ways than by concentrating all the resonances at one frequency. The importance of the higher frequencies in transmitting and reproducing the transient sounds characteristic of the consonants in speech led to placing more emphasis on these frequencies and attempting to produce more uniformly the band of frequencies which was set as a limit for circuits. This has now been accomplished in a practical fashion in the receiver which is being introduced in 1937.

The effect of this evolution in the design of station instruments may be brought out by a comparison of the over-all response characteristic—that is, the relation of the sound delivered to the ear to the sound available at the transmitter—for a typical telephone connection having in one case, both terminal instruments of the 1920 type and, in the other case, the terminal instruments of the new 1937 type (figure 5). In this typical circuit, the trunk has been taken as free from distortion so that its effect will not influence the indicated performance of the instruments, although the circuit does include 2 22-gauge loops each 3 miles long.

At the resonance point of the old instruments, just over 1,000 cycles, the over-all response in going to the new instruments is reduced by almost 30 decibels while the response in the range from 2,000 to 3,000 cycles is increased by over 20 decibels. In the frequency range from 500 to 2,000 cycles, the circuit employing the older instruments shows a variation of over-all response of over 30 decibels. For the new type, the variation for this same frequency range is reduced to 15 decibels, and, furthermore, this variation of 15 decibels applies approximately for the range of from 250 to 2,750 cycles which was mentioned as the transmission range requirement for the design of new circuits. In regard to the variation of 15 decibels in this frequency range, there is good indication that this response is more desirable than one of no variation, from the standpoint of having the telephone performance approach that of direct air transmission.

In addition to these improvements in frequency response and efficiency, the intensive development program on these instruments has improved materially the stability of the carbon transmitter under service conditions. This is an important factor in extending the useful life of these instruments and in reducing the cost of maintaining the desired transmission performance.

Proposed Recommendations for Measurement of Surge Voltages and Currents

IN THE July 1936 issue of ELECTRICAL ENGINEERING the subcommittee of the AIEE committee on instruments and measurements presented a report giving the revised values for 60-cycle sphere-gap calibrations. The values for impulse voltages, however, were held pending development of instructions for their use. A new report by the same committee now has been made available containing the proposals defining the applications and use of sphere spark gaps for both 60-cycle and impulse measurements. This report also corrects certain errors made in the statement of 60-cycle values as published in July 1936.

The recommendations included in the report were formulated in recognition of a general need for a surge measurement standard from which could be derived necessary measurement technique for the surge-testing codes for apparatus and materials. Particular code requirements will necessitate varying measurement technique, and it is expected that this proposed standard will serve as a source from which can be drawn all the necessary measurement recommendations required. Accordingly, it is urged that it be viewed and used in this way. For specific measurement recommendations applying to a particular apparatus, the test code for that apparatus should be consulted.

When approved by the AIEE standards committee, all of the material contained in the subcommittee report will become a part of the proposed complete revision, now under way, of the present AIEE Standard No. 4, "Measurement of Test Voltage in Dielectric Tests."

Those interested in the subcommittee report on the "Proposed Recommendations for Measurement of Surge Voltages and Currents and the Sphere Gap Calibration Standards" may obtain a complete mimeographed copy, without charge, by writing to H. E. Farrer, secretary AIEE standards committee, 33 West 39th Street, New York, N. Y.

Forty Million Kilowatt-Hours for a Fair

ILLUMINATION PLANS for the 1939 Golden Gate International Exposition on San Francisco Bay call for consumption of an estimated 40 million kilowatt-hours of energy during the 288 days of the fair, from February 18 to December 2, 1939.

The Exposition's site is a 400-acre island, created by dredging in the center of the harbor near the mid-point of the San Francisco–Oakland Bay Bridge. Power will be delivered at a 16,000-kva substation on this "Treasure Island" through 3 submarine cables, each 9,000 feet long, from the mainland. Distribution will be made by 10 miles of 4,000-volt underground 3-phase feeders, approximately 25 miles of streetlighting cable, and an undetermined length of secondary.

Approximately $1,000,000 is budgeted for illumination and electrical installation, and intensive field work will be started in the spring of 1938 after underlying water and sewer lines have been laid. Installation is divided into permanent and temporary classifications, for 3 buildings will remain after the close of the Exposition as air terminal building and hangars for the municipal airport that will take over the island. Other buildings will be razed. Decorative installations will use knob-and-tube work, but all interior wiring will be in conduits.

Exterior lighting, expected to set new standards of beauty, has been worked out by a committee of illumination engineers. The plan calls for extensive use of the new "fluorescent tube," a development not yet on the market. These 15-watt gas-filled tubes, mounted in trough reflectors and used for floodlighting, give spectacular effects particularly in pink, blue, green, and white.

Searchlight scintillators, marching cylindrical lanterns, moonlighting, flush lights, steam urns, and water effects have their necessary place in the night picture, and unusual methods of their use are being worked out. At some points, as in the Court of Reflections, lighting will be restrained to encourage a placid mood for greater enjoyment of the scene; at other points, such as the 40-acre Midway, the only restrictions will be against excessively bright exposed lamps that would violate the harmony of the whole.

"Stunts" will be few in number, for the intention is to create a pastel picture of mystery and fantasy, aiding in the interpretation of the basic creation of architects, landscape artists, sculptors, and colorists. Utilitarian roadway lighting will be so designed that it will not detract from the illusion of a white "jeweled city" floating upon the water, and the $50,000,000 fair will be blended into an artistic architectural unit by day or night, rather than a disconnected assemblage of exhibit buildings.

Architecturally, the Exposition will be a series of masses carried toward the skyline by stepped setbacks. These setbacks will be flooded in varying intensities or graduated colors to preserve their positions, with the monotony of normal floodlighting broken by highlights or color changes based upon flags, niches, and architectural elements. Flatness will be relieved also by large circles of color, by the shadows of palm trees, and by ultraviolet radiation playing from concealed projectors on fluorescent paint.

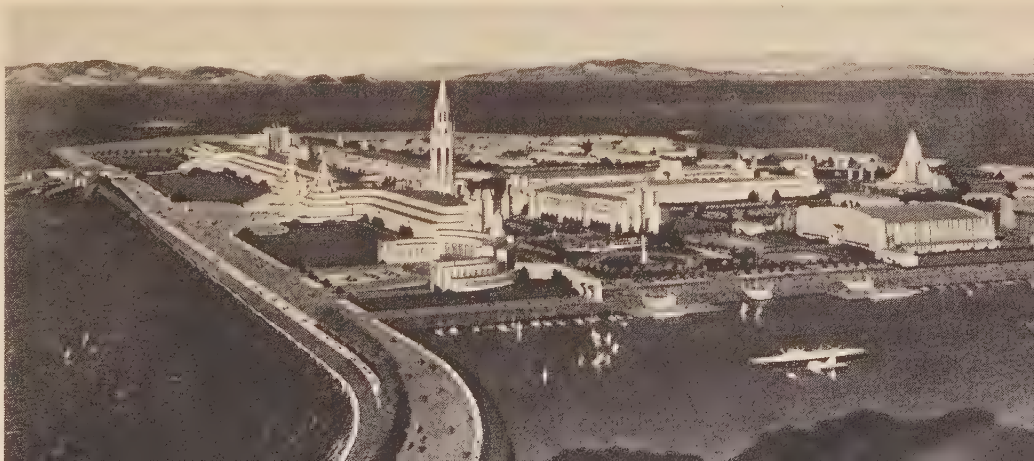
Trees generally will be treated as dark masses, or as silhouettes against glowing backgrounds. Lip lighting and jets will mark the rims of pools, and a feature will be a reproduction in the Port of the Trade Winds of Old Faithful geyser, playing to its full height of 150 feet at brief intervals and lighted by searchlights in changes. At the opposite end of the mile-long island will be an aurora of scintillator beams, created by 24 arc searchlights of 36-inch diameter.

Supplemental to standard lighting will be a power system for stage and spot lighting which can be adapted to special pageants as required. Interiors of exhibit buildings will be illuminated uniformly by day and night, with no windows to mar the planned effectiveness of displays. A spectacular feature in several courts will be cylindrical lanterns, from 60 to 75 feet high and 6 feet in diameter, lighted by concealed tubes within.

Colors will be restricted to harmonious groups of 2 or 3 in each court; chiefly employed will be amber, green, red, apricot, blue, peach, gold, pink, and magenta. The 400-foot central tower, an opportunity to the illuminator, will be a light amber at the base, shading into white of increasing intensity toward the spire. It will be topped by a searchlighted phoenix, rising from a bright red illumination at its base. The interior of the tower, viewed through tall arches, will be amber at the base and blend into a rose red at the upper level.

More than $10,000,000 worth of buildings for this 1939 World's Fair are under construction in the fall of 1937, and the programs of governmental and industrial participation are equally advanced. Except for firms planning to erect their own buildings, electrical displays will be concentrated in a hall of electricity and communication. Central co-ordinating displays planned for this phase of the exhibit program include great relief maps of the Pacific area, painted by "black light" on fluorescent paint to develop existing communication and power lines from virgin country in a twinkling.

From a painting by Chesley Bonestell



Monthly Earnings of Engineers, 1929–34

In this, the seventh article[1] of a series reporting a survey of employment in the engineering profession by the United States Bureau of Labor Statistics, data relative to the monthly rate of compensation received by engineers solely for engineering services in which they were engaged at the end of 1929, 1932, and 1934, are presented. Comparisons may be drawn among professional classes, ages, and educational background.

IN 1929, the range in monthly engineering earnings of professional engineers was very great. Some 79 engineers reported earnings of less than $60 per month, while 168 earned more than $1,880 a month. The median monthly earnings of the 28,511 reporting engineers was $289. One-quarter earned more than $415, while only 10 per cent had earnings greater than $609 a month.

Between 1929 and 1934 there were progressive declines in monthly engineering earnings. While the sharpest absolute decreases occurred at the higher levels of earnings, the greatest percentage decreases took place at the lower earnings levels. Almost two-thirds of the decreases occurred between 1929 and 1932.

Comparison of earnings by professional class, without regard to age, and the consequent effect of the varying age distributions shows that in 1929 the upper 10 per cent of mining and metallurgical engineers, highest at this level, reported earnings of not less than $792 per month as against $515 a month for civil engineers, who were lowest at this level. Second in order came chemical and ceramic engineers, followed by mechanical and industrial, and electrical engineers. For the upper 25 per cent of the reporting engineers the order of the professional classes was the same, monthly engineering earnings ranging from not less than $372 for civil engineers to not less than $503 a month for mining and metallurgical engineers. At the middle and lower earnings levels, the differences in earning capacities of the 5 professional classes were less marked, although in each instance mining and metallurgical engineers and electrical engineers occupied the upper and lower extremes, respectively.

In 1932 and 1934 the order of the professional classes at the 2 higher earning levels was essentially the same as that noted for 1929. At the 3 lower earning levels shifts occurred in this order in 1929, and there were further shifts in 1932 and 1934.

On an age basis the 1929 monthly compensation for engineering services of the lowest tenth of reporting engineers was more than twice as high for those in the age group 48 to 55 as for those of 23 years. At the upper 10 per cent earnings level, maximum earnings of $1,050 a month were reached in the sixties. Similarly, at the average and at the upper and lower quarters of earning levels age 60 was the turning point.

For men of identical ages in 1929, 1932, and 1934 the data reveal that the greatest impact of the depression, as far as engineering earnings were concerned, fell upon men with from 2 to 5 years' experience.

Although the 1929 data on engineering earnings evidence an advantage in favor of men who have engineering degrees, this advantage was less clearly defined than was the case with earned annual incomes. However, the extra years of experience which the "other" engineers had while the graduates were in school permitted of their obtaining higher earnings than graduates only up to a point corresponding to 5 years after graduation. Even at 2 years after graduation the differentials in earnings between the 2 groups were slight. Similarly, at 4 years after graduation, while at the median level graduate earnings ranged from $225 for first-degree electrical engineers to $250 a month for first-degree chemical and ceramic engineers, among the "other" engineers they ranged from $200 for engineers with secondary school education to $229 a month for mechanical and industrial engineers with incomplete college courses.

With advancing age there was a considerable advantage in engineering earnings in favor of the graduates. There was also a distinct variation in the earning capacities among both graduate and "other" engineers.

The monthly engineering earnings of graduates continued to increase several years beyond the point of maximum earnings of "other" engineers. The earnings of the latter either remained stable or declined at 30 years after graduation.

While graduates who were $23^1/_2$ in 1929 and $28^1/_2$ in 1934 reported increased earnings for all kinds of engineering, except mining and metallurgical, no increases were reported by any of the "other" engineers of corresponding ages. For older engineers, however, the decreases apparently affected both graduates and "other" engineers in almost equal measure.

For men of identical years of experience, the earnings received in 1934 by both graduates and "other" engineers were all less than those obtained in 1929. The decreases reported by men with 5 years' experience were, in general, greater than those of men with 2 or with from 10 to 37 years' experience.

Scope and Method

The earned annual incomes of any professional group are made up of earnings from professional work plus, in

1. An article prepared by Andrew Fraser, Jr., of the Division of Hours, Wages, and Working Conditions, Bureau of Labor Statistics, United States Department of Labor, which article was published in the November 1937 issue of *Monthly Labor Review*. Articles reporting other phases of this survey were published in ELECTRICAL ENGINEERING as follows: "Professional Aspects of Engineering Education," August 1936, pages 863–7; "Unemployment in the Engineering Profession," February 1937, pages 216–23; "Employment in the Engineering Profession," May 1937, pages 524–31; "Security of Engineering Employment," June 1937, pages 655–61; "Engineering Income and Earnings," September 1937, pages 1089–1104; "Sources of Engineering Income, 1929–34," November 1937, pages 1353–58. A detailed report of the survey will be published later in bulletin form by the Bureau of Labor Statistics.

some cases, those received for other services. They are affected, moreover, by periods of partial or complete unemployment during the year. In this article an analysis[2] is made of the compensation engineers received solely for professional services during periods of employment, based on the monthly rates of earnings reported for all kinds of engineering work combined.

As in the previous analyses of earned annual incomes, it has been necessary to assume that the kind of engineering employment reported for the end of the year was the source of the income for that year.

Monthly Engineering Earnings

Of the 33,852 engineers who reported as of December 31, 1929, that they were professionally active prior to 1930, 28,511, or 84 per cent, stated their average monthly rates for the engineering work in which they were engaged. These 1929 data, together with the adjusted[3] figures for 1932 and 1934, are shown in table I, without regard to age or kind of engineering employment reported.

As in the case of earned annual incomes, the range in the 1929 monthly engineering earnings of professional engineers was very great. While some 79 engineers reported earnings of less than $60 per month, 168 earned more than $1,880 a month. The median monthly earnings of the 28,511 reporting engineers was $289; one-quarter earned more than $415; and only 10 per cent had earnings greater than $609 a month. The lowest 25 per cent of the reporting engineers earned less than $215 a month while the lowest 10 per cent earned less than $162 a month.

Over the period 1929–34 the changes which occurred in monthly engineering earnings were similar to those previously noted in the discussion of earned annual incomes: (1) Earnings progressively declined from 1929 to 1934; (2) the sharpest absolute decreases occurred at the higher levels of earnings, but the greatest percentage decreases took place at the 2 lower income levels; (3) of the respective total decreases, almost two-thirds occurred between 1929 and 1932.

At all levels, however, the changes in monthly engineering earnings were very much less than those for earned annual incomes. This was due to the fact that annual earnings reflect the combined effects of several factors which were operative in the depression years: (1) The decline in engineering earnings; (2) the acute unemployment; (3) the deterioration in the nature of the available nonengineering work; and (4) the large influx of young engineers in the years 1930–34.

Table I. Comparison of 5 Levels of Monthly Engineering Earnings for All Professional Engineers Reporting in 1929, 1932, and 1934

Figures derived from adjusted data as explained on this page, and without regard to kind of engineering employment reported or type of education

Per Cent at Specific Earning Level	Monthly Engineering Earnings of More Than Specified Amount			Amount of Decrease			Per Cent of Decrease		
	1929	1932	1934	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34
10 per cent	$609	$484	$435	$174	$125	$49	28.6	20.5	10.1
25 per cent	415	334	304	111	81	30	26.7	19.5	9.0
50 per cent	289	235	210	79	54	25	27.3	18.7	10.6
75 per cent	215	167	148	67	48	19	31.2	22.3	11.4
90 per cent	162	123	112	50	39	11	30.9	24.1	8.9

Clearly, earned annual income data cannot be used as a measure of the rates at which engineering services were purchased. Illustrative of this is the fact that in 1929 only at the 2 higher earnings levels did earned annual income exceed 12 times the monthly earnings reported solely from engineering services. In the years 1932 and 1934, the estimated annual earnings from engineering work only were greater at all 5 income levels. But while the lowest 10 per cent of the reporting engineers had earned annual incomes of not less than $872 in 1934, the monthly rate of earnings at this level shows a possible income of not less than $1,344 a year from engineering work.

More particularly, however, while the lowest 10 per cent of the reporting engineers engaged in engineering work in 1929 had earned not less than $162 per month, by 1934 the monthly earnings at this level were not less than $112. This was a decline of 30.9 per cent. By contrast, the earned annual incomes of a similar proportion of engineers had declined by 53.6 per cent. At the next highest income level, engineering earnings decreased by 31.2 per cent, as against 41.3 per cent in the case of earned annual incomes. Similarly, average monthly engineering earnings dropped by 27.3 per cent, whereas annual incomes declined by 33.0 per cent. This decline in the average earnings differed but little from those which occurred at the upper 10 and 25 per cent of the reporting engineers, namely, 28.6 and 26.7 per cent, respectively. The corresponding decreases in annual incomes of similar proportions of engineers were 31.2 and 31.6 per cent. In other words, while the range in the decline in engineering earnings was from 26.7 to 31.2 per cent, it was from 31.2 to 53.6 per cent for annual incomes.

The findings and comments of the preceding analysis

2. See "Engineering Income and Earnings, 1929–34," Electrical Engineering for September 1937, pages 1089–1104, for details of the scope and methods of analysis.

3. The procedure of adjustment adopted was similar to that outlined in the "Employment in the Engineering Profession," 1929 to 1934, Electrical Engineering, May 1937, pages 524–31. The numbers of younger engineers reporting in each income class for 1932 and 1934 were reduced in the ratio of 15 to 32 and added to the corresponding figures reported by the older engineers in 1932 and 1934.

also apply to the engineering earnings reported by the 5 professional classes. These are shown, also without regard to age[4] or kind of engineering employment, in table II.

In 1929, the upper 10 per cent of mining and metallurgical engineers, highest at this level, had earnings of not less than $792 per month as against $515 for civil engineers, who were lowest at this level. Second in order came chemical and ceramic engineers, of whom the upper 10 per cent had monthly earnings of not less than $732, followed by mechanical and industrial engineers, and electrical engineers, respectively, with not less than $674 and $587 a month. For the upper 25 per cent of the reporting engineers the order of the professional classes was the same, monthly earnings ranging from not less than $372 for civil engineers to not less than $503 a month for mining and metallurgical engineers. At the middle and 2 lower earnings levels, the differences in earning capacity were less marked. However, in each instance mining and metallurgical engineers and electrical engineers occupied the upper and lower extremes, respectively. Civil engineers shifted from fourth place at the average earnings level to second at the lowest earnings level, while chemical and ceramic engineers shifted from second to fourth place. The ranges in monthly earnings over these 3 levels were, respectively, from not less than $275 to $334, $201 to $241, and $148 to $186.

Despite the progressive declines in engineering earnings between 1929 and 1934, the orders of the professional classes at the 2 higher levels were essentially the same as those noted for 1929. However, at the middle earnings level, chemical and ceramic engineers had dropped from second place in 1929 and 1932 to fifth by 1934; but even in 1934 their monthly engineering earnings were practically the same as those of the civil engineers, who were fourth in order. Mining and metallurgical engineers were highest both in 1932 and 1934. Thus in the latter year, while their median earnings were $241 a month, those of both mechanical and industrial engineers and electrical engineers were $215 a month.

At the lowest 25 per cent earnings level of the reporting engineers, the lowest and highest figures for 1932 and 1934 were again reported, respectively, by chemical and ceramic engineers and mining and metallurgical engineers. At the same level in 1934 the range was from not less than $131 for chemical and ceramic engineers to not less than $154 for mining and metallurgical engineers. This reduction in the range of earnings was more pronounced at the lowest earnings level both in 1932 and 1934, for while in the former year it was from not less than $116 to not less than $126, in the latter it was from not less than $101 to

Table II. Comparison of 5 Levels of Monthly Engineering Earnings for All Engineers Reporting in Each Professional Class in 1929, 1932, and 1934

Figures derived from adjusted data as explained on page 1451, and without regard to kind of engineering employment reported or type of education

	Monthly Engineering Earnings of More Than Specified Amount			Amount of Decrease			Per Cent of Decrease		
Per Cent of Professional Class at Specified Earning Level[1]	1929	1932	1934	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34
10 per cent:									
Mining and metallurgical	$792	$585	$524	$268	$207	$61	33.8	26.1	10.4
Chemical and ceramic	732	579	509	223	153	70	30.5	20.9	12.1
Mechanical and industrial	674	512	441	233	162	71	34.6	24.0	13.9
Electrical	587	496	463	124	91	33	21.1	15.5	6.7
Civil, agricultural, and architectural	515	430	390	125	85	40	24.3	16.5	9.3
25 per cent:									
Mining and metallurgical	503	409	371	132	94	38	26.2	18.7	9.3
Chemical and ceramic	490	400	339	151	90	61	30.8	18.4	15.2
Mechanical and industrial	455	356	313	142	99	43	31.2	21.8	12.1
Electrical	405	336	315	90	69	21	22.2	17.0	6.2
Civil, agricultural, and architectural	372	311	279	93	61	32	25.0	16.4	10.3
50 per cent:									
Mining and metallurgical	334	274	241	93	60	33	27.8	18.0	12.0
Chemical and ceramic	326	251	203	123	75	48	37.7	23.0	19.1
Mechanical and industrial	311	246	215	96	65	31	30.9	20.9	12.6
Civil, agricultural, and architectural	277	229	205	72	48	24	26.0	17.3	10.5
Electrical	275	232	215	60	43	17	21.8	15.6	7.3
75 per cent:									
Mining and metallurgical	241	183	154	87	58	29	36.1	24.1	15.8
Mechanical and industrial	225	166	145	80	59	21	35.6	26.2	12.7
Chemical and ceramic	221	157	131	90	64	26	40.7	29.0	16.6
Civil, agricultural, and architectural	213	169	150	63	44	19	29.6	20.7	11.2
Electrical	201	163	148	53	38	15	26.4	18.9	9.2
90 per cent:									
Mining and metallurgical	186	125	115	71	61	10	38.2	32.8	8.0
Civil, agricultural, and architectural	167	126	120	47	41	6	28.1	24.6	4.8
Mechanical and industrial	167	122	107	60	45	15	35.9	26.9	12.3
Chemical and ceramic	156	116	101	55	40	15	35.3	25.6	12.9
Electrical	148	123	108	40	25	15	27.0	16.9	12.2

1. Arranged in ascension of monthly engineering earnings for 1929.

4. It is important to note that any data concerning the several professional classes as a whole without regard to age tend to obscure the effects of different age distributions within the classes. Those classes with a relatively high proportion of older men for this reason are likely to show relatively high earnings, and those with relatively more younger men to show smaller earnings.

Table III. Comparison of 5 Levels of Monthly Engineering Earnings, on Age Basis, for All Engineers Reporting in 1929, 1932, and 1934

Without regard to kind of engineering employment reported or type of education

Age	Year of Graduation	Years After Graduation	Proportion With Monthly Engineering Earnings of More Than Specified Amount				
			10 Per Cent	25 Per Cent	50 Per Cent	75 Per Cent	90 Per Cent
			1929				
64 years and over	Prior to 1889	40 and over	$820	$601	$388	$263	$194
56–63 years	1889–96	33–40	1,050	628	425	296	210
48–55 years	1897–1904	25–32	933	592	414	297	232
40–47 years	1905–12	17–24	789	514	385	289	229
36–39 years	1913–16	13–16	630	467	339	269	218
32–35 years	1917–20	9–12	519	407	310	249	208
28–31 years	1921–24	5–8	4 4	317	262	217	187
26–27 years	1925–26	3–4	307	256	218	186	155
24–25 years	1927–28	1–2	252	215	181	152	133
23 years	1929	0	215	174	149	130	115
			1932				
67 years and over	Prior to 1889	44 and over	$725	$499	$331	$216	$144
59–66 years	1889–96	36–43	751	517	352	241	152
51–58 years	1897–1904	28–35	707	486	340	241	164
43–50 years	1905–12	20–27	624	433	315	234	168
39–42 years	1913–16	16–19	517	396	295	223	170
35–38 years	1917–20	12–15	458	349	272	211	157
31–34 years	1921–24	8–11	358	293	234	189	143
29–30 years	1925–26	6–7	299	244	205	166	135
27–28 years	1927–28	4–5	250	215	181	147	119
26 years	1929	3	221	185	156	134	110
25 years	1930	2	190	161	143	122	101
24 years	1931	1	173	149	126	104	84
23 years	1932	0	165	137	111	89	66
			1934				
69 years and over	Prior to 1889	46 and over	$620	$430	$284	$173	$108
61–68 years	1889–96	38–45	711	480	321	205	126
53–60 years	1897–1904	30–37	650	447	310	212	146
45–52 years	1905–12	22–29	592	413	292	214	152
41–44 years	1913–16	18–21	505	375	273	205	150
37–40 years	1917–20	14–17	440	336	254	197	148
33–36 years	1921–24	10–13	354	285	224	177	139
31–32 years	1925–26	8–9	299	238	199	161	133
29–30 years	1927–28	6–7	253	215	177	145	118
28 years	1929	5	228	191	162	138	113
27 years	1930	4	199	172	148	125	104
26 years	1931	3	182	156	137	114	94
25 years	1932	2	169	145	124	103	84
24 years	1933	1	159	138	116	98	82
23 years	1934	0	149	129	110	91	75

not less than $120, the upper and lower extremes being reported, respectively, by the civil engineers and the chemical and ceramic engineers.

The decline in engineering earnings of each professional class was very much less than that which occurred in earned annual incomes. The greatest percentage decreases took place at the 2 lower levels. For example, while engineering earnings of electrical engineers at these limits declined by 26.4 and 27.0 per cent, the corresponding annual incomes decreased by 42.6 and 56.0 per cent. In the case of chemical and ceramic engineers, the drops in earnings at these levels were 40.7 and 35.3 per cent as against 52.2 and 63.8 per cent in their annual incomes.

Monthly Engineering Earnings Related to Age

In table III there are presented the monthly engineering earnings, by age,[5] of all engineers combined and without regard to kind of engineering employment.

As shown in table III there was, in general, a steady advance in monthly earnings at all levels up to the highest age groups. Except for the absence of the exceptionally rapid rise from 23 to 25 years, the changes with age in monthly engineering earnings at all 5 levels show no marked differences from those derived from the analysis of earned annual incomes by age. Thus, in 1929 the compensation for engineering services of the lowest tenth of the reporting engineers steadily increased from over $115 a month for those 23 years to a maximum of over $232 a month for those who were between 48 and 55 years. At each of the 4 higher earning levels maximum earnings were reached some 8 years later, or near to age 60. The respective maxima were not less than $297, $414, $592, and $1,050 per month. Even for engineers 23 years of age there was a considerable spread in earnings. This is evidenced by the fact that at the average level the earnings were not less than $149 a month, above this one-quarter earned over $174, and one-tenth over $215 per month, as against monthly engineering earnings of over $130 and $115 at the two lower levels.

The spread in engineering earnings with advancing age became quite marked at the age of 30; that is, some 8

5. Throughout the ensuing discussion age and years after graduation are used interchangeably. Of course in the case of nongraduates (that is "other engineers") age only applies. The relationship between these 2 factors can readily be derived from the fact that the median age of graduation of new graduates to the profession was found to be 23 years.

Table IV. Comparison of 5 Levels of Monthly Engineering Earnings on Age Basis for All Graduate Engineers Reporting in 1929, 1932, and 1934

Without regard to kind of engineering employment reported or type of education

Age	Year of Graduation	Years After Graduation	Proportion With Monthly Engineering Earnings of More Than Specified Amount				
			10 Per Cent	25 Per Cent	50 Per Cent	75 Per Cent	90 Per Cent
1929							
64 years and over	Prior to 1889	41 and over	$880	$624	$417	$302	$215
56–63 years	1889–96	33–40	1,152	661	472	326	243
48–55 years	1897–1904	25–32	1,018	625	434	319	252
40–47 years	1905–12	17–24	826	552	410	306	245
36–39 years	1913–16	13–16	663	490	356	286	231
32–35 years	1917–20	9–12	540	416	321	263	218
28–31 years	1921–24	5–8	410	322	269	223	196
26–27 years	1925–26	3–4	308	260	220	189	160
24–25 years	1927–28	1–2	247	213	180	152	135
23 years	1929	0	205	169	148	130	115
1932							
67 years and over	Prior to 1889	44 and over	$778	$519	$350	$234	$173
59–66 years	1889–96	36–43	807	558	401	277	170
51–58 years	1897 1904	28–35	739	505	374	265	185
43–50 years	1905–12	20–27	653	458	334	248	178
39–42 years	1913–16	16–19	557	419	312	240	187
35–38 years	1917–20	12–15	480	365	288	223	171
31–34 years	1921–24	8–11	368	301	241	198	149
29–30 years	1925–26	6–7	302	251	210	172	141
27–28 years	1927–28	4–5	253	217	183	149	122
26 years	1929	3	219	184	156	135	113
25 years	1930	2	187	160	143	122	101
24 years	1931	1	171	148	125	104	84
23 years	1932	0	159	134	110	88	64
1934							
69 years and over	Prior to 1889	46 and over	$636	$480	$307	$205	$110
61–68 years	1889–96	38–45	770	517	360	232	132
53–60 years	1897–1904	30–37	704	478	337	229	152
45–52 years	1905–12	22–29	626	431	313	226	158
41–44 years	1913–16	18–21	533	404	294	219	161
37–40 years	1917–20	14–17	461	354	271	210	157
33–36 years	1921–24	10–13	360	294	232	186	145
31–32 years	1925–26	8–9	303	242	205	169	140
29–30 years	1927–28	6–7	258	218	181	148	121
28 years	1929	5	228	192	164	140	115
27 years	1930	4	200	172	149	126	105
26 years	1931	3	180	156	137	114	94
25 years	1932	2	169	145	124	102	84
24 years	1933	1	159	137	116	98	82
23 years	1934	0	149	129	109	91	75

years earlier than was the case for earned annual incomes. (See figure 1.) Again the earnings of the upper 10 per cent of reporting engineers diverged sharply from those at corresponding ages in the lower levels. Thus, at age 44 the former were greater than the average by some 102 per cent, as against a corresponding difference at the upper 25 per cent level of only 33 per cent. At age 60, the respective differences were 144 and 48 per cent.

These general relationships of monthly engineering earnings by age of all engineers[6] reporting also held in the years 1932 and 1934, as well as for the monthly earnings of all graduates[7] shown in table IV.

Consideration will now be given to the extent to which monthly engineering earnings may have been affected by the depression. Reference, however, will be made only to the data reported by all graduate and "other" engineers combined.

For men of advancing years and experience, it appears from the data presented in table V that over the period 1929–34 only those engineers who were $23^1/_2$ years in 1929 and $28^1/_2$ in 1934 reported increased earnings. Earnings of the next higher age group showed practically no change. For succeeding age groups the declines in earnings were progressively greater. Thus, while there was a 15 per cent decrease between 1929 and 1934 at the middle level of earnings of engineers who were 30 in 1929 and 35 in 1934, the decrease was as high as 24 per cent for engineers who were 65 years of age in 1934. A similar situation existed at the other four earnings levels, for all engineers, and also for graduate engineers only, as shown in table VI.

One important aspect of these engineering earnings is that it is now possible to determine the compensation younger engineers received for their engineering services. This information could not be obtained from the data on earned annual incomes for reasons previously cited. The principal reason, however, was that most engineers 23 years of age could not have worked a full year.[8] Many of

6. That is, graduates and "other" engineers combined.

7. That is, postgraduates, nonengineering graduates, and first-degree engineering graduates combined.

8. This qualification applies only to graduate engineers, for in the case of "other" engineers many of them could have been working for a year or more

the graduates estimated what their annual earnings would have been, based on what they had earned for the first 6 months after graduation. Obviously, this necessity for estimating does not apply to the monthly earnings for engineering work. Hence, the monthly earnings data are the most accurate indication of what the rates of compensation of younger engineers were for engineering work. This situation is best exemplified by considering the earnings reported by men who were of identical ages in 1929, 1932, and 1934, as presented in tables VII and VIII.

These data reveal the fact that the newcomers to the profession suffered less than those with from 2 to 5 years' experience in engineering. Thus, while median monthly earnings of the newcomers were 26 per cent less in 1934 than those of men of similar ages in 1929, they were 34 per cent less in the case of men with from 2 to 5 years' experience in each of these years. But it will also be noted that the declines in earnings of engineers between 1929 and 1934 with from 20 to 37 years of experience were practically the same as those reported by engineers 23½ years of age. Furthermore, a similar relationship existed at the 4 other earnings levels, despite the fact that the declines in earnings were relatively greater in the case of engineers at the 2 lower earnings levels.

It will be recalled that in the discussion of employment status that as far as available engineering work was concerned, the tendency appeared to be to give preference to engineers who entered the profession in the period 1930–34. The analysis of the data in the table VII shows that it was not those engineers who entered the profession in 1934 who suffered relatively the greatest cuts but those who had entered during one or other of the depression years, 1930–33, inclusive. Similarly, data for earnings of graduates of identical ages are shown in table VIII.

Engineering Earnings and Education

Of all engineers who furnished information on the monthly rates of compensation received by them for engi-

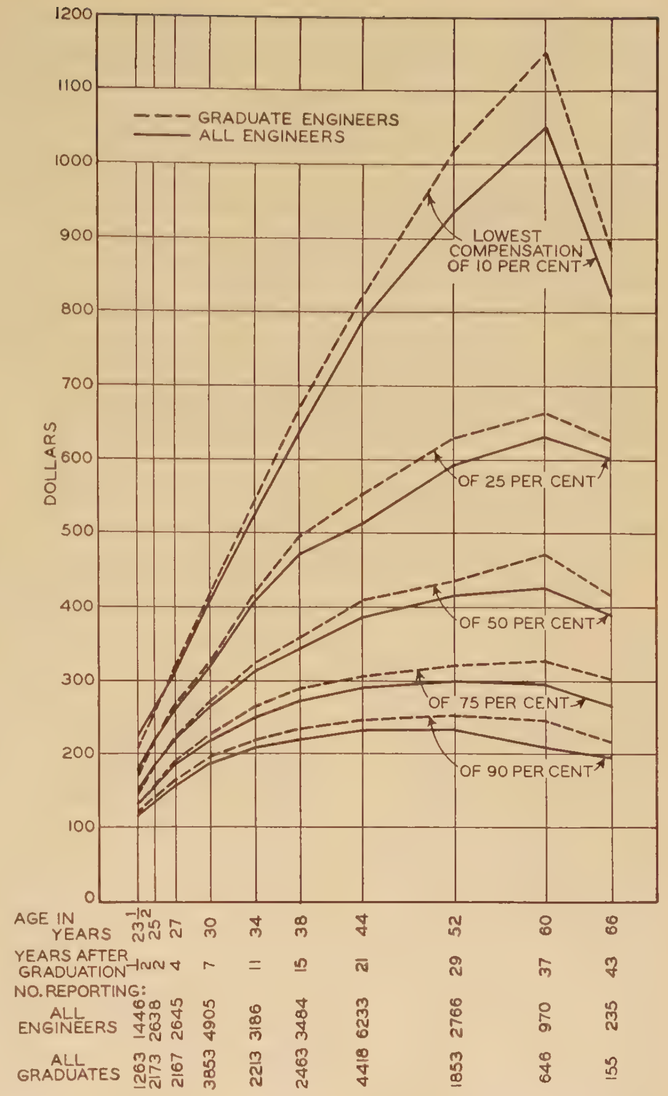


Figure 1. Chart of monthly compensation of professional engineers in engineering work by age in 1929

Includes compensation for all kinds of engineering services studied

Table V. Comparison of 5 Levels of Monthly Engineering Earnings for 5 Age Groups of Older[1] Engineers Reporting in 1929, 1932, and 1934

Without regard to kind of engineering employment reported or type of education

Per Cent at Specified Income Level	Monthly Engineering Earnings of More Than Specified Amount of Engineers Whose Age Was														
	60 in 1929	63 in 1932	65 in 1934	38 in 1929	41 in 1932	43 in 1934	30 in 1929	33 in 1932	35 in 1934	25 in 1929	28 in 1932	30 in 1934	23½ in 1929	26½ in 1932	28½ in 1934
10 per cent	$1,050	$751	$711	$630	$517	$505	$404	$358	$354	$252	$250	$253	$215	$221	$228
25 per cent	628	517	480	467	396	375	317	293	285	215	215	215	174	185	191
50 per cent	425	352	321	339	295	273	262	234	224	181	181	177	149	156	162
75 per cent	296	241	205	269	223	205	217	189	177	152	147	145	130	134	138
90 per cent	210	152	126	218	170	150	187	143	139	133	119	118	115	110	113
	Per Cent of Increase or Decrease														
	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34
10 per cent	−32	−28	− 5	−20	−18	− 2	−12	−11	−1	0	− 1	+1	+ 6	+3	+3
25 per cent	−24	−18	− 7	−20	−15	− 5	−10	− 8	−3	0	0	0	+10	+6	+3
50 per cent	−24	−17	− 9	−19	−13	− 7	−15	−11	−4	− 2	0	−2	+ 9	+5	+4
75 per cent	−31	−19	−15	−24	−17	− 8	−18	−13	−6	− 5	− 3	−1	+ 6	+3	+3
90 per cent	−40	−28	−17	−31	−22	−12	−26	−24	−3	−11	−11	−1	− 2	−4	+3

1. Includes those engineers who were professionally active prior to 1930.

neering services in 1929, 21,205 were graduates and 7,305 were "other" engineers. The former number represented 86 per cent of the 24,837 graduates, and the latter covered 81 per cent of the 9,015 "other" engineers who reported that they were professionally active prior to 1930. A comparison of the engineering earnings of these 2 groups is shown, without regard to age and kind of engineering employment reported, in table IX.

Although the figures in the third from the last column in table IX indicate an advantage in favor of those men who have engineering degrees, this advantage is less clearly defined than was indicated in the similar analysis of earned annual incomes. This is evidenced by the fact that only at the highest earnings level did the earnings of graduates of all 5 professional classes exceed those of "other" engineers. Even at this level, the advantage did not accrue in equal measure for each of the 5 professional classes.

Thus, while the monthly earnings of the upper one-tenth of the mining and metallurgical graduates exceeded those of the upper tenth of the "other" engineers by $94 a month, the differences in monthly engineering earnings among the 4 remaining professional classes ranged from $31 for mechanical and industrial engineers to $61 for chemical and ceramic engineers. At the upper 25 per cent level, the engineering earnings of mechanical and industrial graduates and "other" engineers were practically the same. There was a difference of only $13 between the earnings of the 2 groups in the case of mining and metallurgical engineers, and for electrical engineers the difference was only

Table VI. Comparison of 5 Levels of Monthly Engineering Earnings for 5 Age Groups of Older[1] Graduate Engineers Reporting in 1929, 1932, and 1934

Without regard to kind of engineering employment reported or type of education

Per Cent at Specified Income Level	Monthly Engineering Earnings of More Than Specified Amount of Engineers Whose Age Was														
	60 in 1929	63 in 1932	65 in 1934	38 in 1929	41 in 1932	43 in 1934	30 in 1929	33 in 1932	35 in 1934	25 in 1929	28 in 1932	30 in 1934	23½ in 1929	26½ in 1932	28½ in 1934
10 per cent	$1,152	$807	$770	$663	$557	$533	$410	$368	$360	$247	$253	$258	$205	$219	$228
25 per cent	661	558	517	490	419	404	322	301	294	213	217	218	169	184	192
50 per cent	472	401	360	356	312	294	269	241	232	180	183	181	148	156	164
75 per cent	326	277	232	286	240	219	223	198	186	152	149	148	130	135	140
90 per cent	243	170	132	231	187	161	196	149	145	135	122	121	115	113	115

	Per Cent of Increase or Decrease														
	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34
10 per cent	−33	−30	− 5	−20	−16	− 4	−12	−10	−2	+ 4	+ 2	+2	+11	+7	+4
25 per cent	−22	−16	− 7	−18	−14	− 4	− 9	− 7	−2	+ 2	+ 2	0	+14	+9	+4
50 per cent	−24	−15	−10	−17	−12	− 6	−14	−10	−4	+ 1	+ 2	−1	+11	+5	+5
75 per cent	−29	−15	−16	−23	−16	− 9	−17	−11	−6	− 3	− 2	−1	+ 8	+4	+4
90 per cent	−46	−30	−22	−30	−19	−14	−26	−24	−3	−10	−10	−1	0	−2	+2

1. Includes those engineers who were professionally active prior to 1930.

Table VII. Comparison of 5 Levels of Monthly Engineering Earnings of All Engineers for Corresponding Years After Graduation in 1929, 1932, and 1934

Without regard to kind of engineering employment reported or type of education

Age of Engineers	Years After Graduation	Proportion With Monthly Engineering Earnings of More Than Specified Amount														
		10 Per Cent			25 Per Cent			50 Per Cent			75 Per Cent			90 Per Cent		
		1929	1932	1934	1929	1932	1934	1929	1932	1934	1929	1932	1934	1929	1932	1934
23½ years	½	$215	$165	$149	$174	$137	$129	$149	$111	$110	$130	$ 89	$ 91	$115	$ 66	$ 75
25 years	2	252	180	160	215	152	140	181	133	120	152	114	102	133	92	82
28 years	5	339	250	210	276	215	187	231	181	153	196	147	130	167	119	109
33 years	10	485	358	314	386	293	248	299	234	205	239	189	162	202	143	134
43 years	20	741	559	505	501	405	375	375	301	273	283	227	205	229	169	150
53 years	30	940	685	617	592	462	428	416	332	299	296	240	211	230	164	148
60 years	37	1,050	733	670	628	497	459	425	349	313	296	242	209	210	157	137

		Per Cent of Increase or Decrease														
		1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34
23½ years	½	−31	−23	−10	−26	−21	− 6	−26	− 6	− 1	−30	−32	+ 2	−35	−43	+14
25 years	2	−37	−29	−11	−35	−29	− 8	−34	−27	−10	−33	−25	−11	−38	−31	−11
28 years	5	−38	−26	−16	−32	−22	−13	−34	−22	−15	−34	−25	−12	−35	−29	− 8
33 years	10	−35	−26	−12	−36	−24	−15	−31	−22	−12	−32	−21	−14	−34	−29	− 6
43 years	20	−32	−25	−10	−25	−19	− 7	−27	−20	− 9	−28	−20	−10	−34	−26	−11
53 years	30	−34	−27	−10	−28	−22	− 7	−28	−20	−10	−29	−19	−12	−36	−29	−10
60 years	37	−36	−30	− 9	−27	−21	− 8	−26	−18	−10	−29	−18	−14	−35	−25	−13

Table VIII. Comparison of 5 Levels of Monthly Engineering Earnings of All Graduate Engineers for Corresponding Years After Graduation in 1929, 1932, and 1934

Age of Engineers	Years After Graduation	Proportion With Monthly Engineering Earnings of More Than Specified Amount														
		10 Per Cent			25 Per Cent			50 Per Cent			75 Per Cent			90 Per Cent		
		1929	1932	1934	1929	1932	1934	1929	1932	1934	1929	1932	1934	1929	1932	1934
23½ years	½	$205	$159	$149	$169	$134	$129	$148	$110	$109	$130	$ 88	$ 91	$115	$ 64	$ 75
25 years	2	247	180	161	213	153	140	180	132	119	152	112	100	135	93	82
28 years	5	339	253	210	280	217	184	238	183	155	199	149	132	170	122	110
33 years	10	500	368	320	389	301	260	309	241	212	252	198	174	211	149	132
43 years	20	797	583	533	539	428	404	400	320	294	301	241	219	243	181	161
53 years	30	1,030	715	664	628	497	451	440	365	326	320	260	228	253	182	156
60 years	37	1,152	780	729	661	539	489	472	394	348	326	271	230	243	175	146
		Per Cent of Increase or Decrease														
		1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34
23½ years	½	−27	−22	− 6	−24	−21	− 4	−26	−26	− 1	−30	−32	+ 3	−35	−44	+17
25 years	2	−35	−27	−11	−34	−28	− 8	−34	−27	−10	−34	−26	−11	−39	−31	−12
28 years	5	−38	−25	−17	−34	−23	−15	−35	−23	−15	−34	−25	−11	−35	−28	−10
33 years	10	−36	−26	−13	−33	−23	−14	−31	−22	−12	−31	−21	−12	−37	−29	−11
43 years	20	−33	−27	− 9	−25	−21	− 6	−27	−20	− 8	−27	−20	− 9	−34	−26	−11
53 years	30	−36	−31	− 7	−28	−21	− 9	−26	−17	−11	−29	−19	−12	−38	−28	−14
60 years	37	−37	−32	− 7	−26	−18	− 9	−26	−17	−12	−29	−17	−15	−40	−28	−17

Table IX. Comparison of 5 Levels of Monthly Engineering Earnings for Older[1] Graduate and "Other" Engineers Reporting in Each Professional Class in 1929, 1932, and 1934

Without regard to kind of engineering employment reported

Per Cent of Professional Class at Specified Earnings Level[2]	Monthly Engineering Earnings of More Than Specified Amount						Per Cent Earnings of "Other" Engineers Formed of Those of Graduate Engineers		
	Graduate Engineers[3]			"Other" Engineers[4]					
	1929	1932	1934	1929	1932	1934	1929	1932	1934
10 per cent:									
Mining and metallurgical	$803	$617	$612	$709	$501	$512	88	81	84
Chemical and ceramic	737	636	632	676	596	553	92	94	88
Mechanical and industrial	684	537	514	653	511	495	95	95	96
Electrical	594	516	505	557	504	482	94	98	95
Civil, agricultural, and architectural	544	463	427	478	385	352	88	83	82
25 per cent:									
Mining and metallurgical	506	423	413	493	403	392	97	95	95
Chemical and ceramic	494	433	426	433	408	365	88	94	86
Mechanical and industrial	454	385	362	455	364	341	100	95	94
Electrical	408	357	352	386	336	319	95	94	91
Civil, agricultural, and architectural	397	336	313	335	290	268	84	86	86
50 per cent:									
Mining and metallurgical	337	290	280	318	274	260	94	94	93
Chemical and ceramic	329	297	290	307	289	260	93	97	90
Mechanical and industrial	308	265	249	317	262	236	103	99	95
Civil, agricultural, and architectural	287	249	231	258	224	206	90	90	89
Electrical	276	252	246	272	238	229	99	94	93
75 per cent:									
Mining and metallurgical	240	202	197	246	197	186	103	98	94
Chemical and ceramic	222	206	203	216	206	185	97	100	91
Mechanical and industrial	219	188	180	243	188	171	111	100	95
Civil, agricultural, and architectural	217	190	177	207	174	156	95	92	88
Electrical	199	187	187	206	179	168	104	96	90
90 per cent:									
Mining and metallurgical	185	142	145	195	132	135	105	93	93
Civil, agricultural, and architectural	169	143	140	164	131	128	97	92	91
Mechanical and industrial	160	138	136	192	134	125	120	97	92
Chemical and ceramic	156	150	146	154	121	129	99	81	89
Electrical	145	145	144	159	128	126	110	89	88

1. Includes all engineers who reported they were professionally active prior to 1930.
2. Arranged in ascension of graduate monthly engineering earnings for 1929.
3. Graduate engineers embrace all postgraduates, nonengineering graduates, and final-degree engineering graduates.
4. "Other" engineers embrace all engineers with college course incomplete, noncollegiate technical school course, and secondary school education.

$22 a month. However, at this level, in the case of chemical and ceramic engineers and civil engineers the differences were much higher, being $61 and $62 per month, respectively.

At these 2 earnings levels, the relationships between the earnings of graduates and "other" engineers in 1932 and 1934 were similar to those just noted for 1929.

At the average and at the 2 lower levels of earnings, the ratios of engineering earnings of the 2 groups of engineers were practically the same as those noted for earned an-

nual incomes. That is, in 1929 there was a slight advantage in favor of the "other" engineers, which was maintained to a somewhat greater degree in 1932 and 1934 than was the case for earned annual incomes. In part, however, this advantage in earnings of "other" engineers was due primarily to a higher age among the nongraduates in the groups compared.

The advantages in increased earning capacity accruing from formal education are better seen in table X, which shows the engineering earnings by type of education and by age. Only the median earnings are given, as insufficient data were obtained for the 2 lower and the 2 higher earnings levels to enable a complete comparison for all age groups and types of education.

The extra years of experience which the "other" engineers had while the graduates were in school permitted of their obtaining higher earnings than graduates only up to a point corresponding to 5 years after graduation. Even at 2 years after graduation in 1929 the differentials in earnings between the 2 groups were slight. Thus, while the median monthly earnings of "other" engineers ranged from $183 for secondary-school engineers to $193 for mechanical engineers whose college course was incomplete, the earnings of graduates from engineering work ranged from $166 per month for those with a nonengineering education to $187 for first-degree civil engineers. At 4 years after graduation, as will be seen from figure 2, the graduates were beginning to pull ahead of the "other" engineers.

Table X. Median Monthly Engineering Earnings in 1929, 1932, and 1934, for All Engineers Reporting by Age and Type of Education

Without regard to kind of engineering employment reported

					First-Degree Engineering Graduates					Others With— College Course Incomplete		Others With— Noncollegiate Technical Course		
Age	Year of Graduation	Years After Graduation	Postgraduates	Nonengineering Graduates	Chemical and Ceramic	Civil, Agricultural, and Architectural	Electrical	Mechanical and Industrial	Mining and Metallurgical	Civil, Agricultural, and Architectural	Mechanical and All Others	Civil, Agricultural, and Architectural	Mechanical and All Others	Secondary-School Education
			1929 Earnings (in Dollars)											
64 and over	[1]	41+	[2]	480	[2]	408	[2]	410	440	310	440	[2]	[2]	320
56–63	1889–96	33–40	484	493	510	424	484	506	493	315	420	347	380	360
48–55	1897–04	25–32	455	482	493	407	438	483	437	318	423	286	402	353
40–47	1905–12	17–24	421	414	523	358	428	440	458	302	401	293	354	308
36–39	1913–16	13–16	350	416	487	328	368	405	405	273	335	260	326	310
32–35	1917–20	9–12	307	335	395	305	338	337	370	257	319	254	290	275
28–31	1921–24	5–8	266	255	295	260	264	285	284	220	267	218	253	233
26–27	1925–26	3–4	220	224	236	220	213	224	235	204	215	210	211	192
24–25	1927–28	1–2	180	166	179	187	167	180	183	184	193	187	186	183
23	1929	0	145	152	150	155	137	141	156	166	178	160	150	160
			1932 Earnings (in Dollars)											
67 and over	[1]	44+	[2]	260	[2]	336	[2]	420	[2]	247	380	[2]	[2]	295
59–66	1889–96	36–43	435	400	[2]	367	415	416	420	273	335	267	300	311
51–58	1897–04	28–35	421	427	420	334	420	390	356	262	333	247	311	311
43–50	1905–12	20–27	365	384	443	307	353	351	374	258	326	249	289	273
39–42	1913–16	16–19	318	353	418	289	330	327	314	235	284	232	270	265
35–38	1917–20	12–15	294	305	324	262	309	301	300	226	263	222	244	234
31–34	1921–24	8–11	249	245	273	232	243	250	239	206	228	193	209	212
29–30	1925–26	6–7	220	227	223	208	202	211	206	187	189	180	180	173
27–28	1927–28	4–5	188	190	185	187	178	175	162	168	174	154	156	168
26	1929	3	157	149	149	164	152	152	149	149	148	163	150	130
25	1930	2	142	149	144	149	136	137	143	156	133	167	140	150
24	1931	1	119	120	124	134	118	120	114	145	131	[2]	135	140
23	1932	0	110	[2]	108	116	103	106	97	143	127	[2]	[2]	[2]
			1934 Earnings (in Dollars)											
69 and over	[1]	46+	[2]	250	[2]	306	[2]	330	[2]	210	310	[2]	[2]	280
61–68	1889–96	38–45	376	370	[2]	331	408	370	400	257	300	256	227	283
53–60	1897–1904	30–37	386	387	426	296	379	346	340	240	320	220	297	298
45–52	1905–12	22–29	339	353	425	285	349	333	347	236	301	227	261	252
41–44	1913–16	18–21	299	384	350	263	333	303	302	218	254	208	247	254
37–40	1917–20	14–17	279	305	340	244	300	283	311	201	247	199	228	229
33–36	1921–24	10–13	241	242	287	218	240	239	237	183	216	183	198	198
31–32	1925–26	8–9	217	208	228	198	205	207	207	166	184	158	180	162
29–30	1927–28	6–7	186	197	198	179	180	180	183	156	170	142	159	153
28	1929	5	166	164	170	163	162	165	153	145	153	160	150	134
27	1930	4	144	145	153	150	145	149	143	145	135	155	133	150
26	1931	3	137	131	134	143	127	132	143	137	145	110	131	153
25	1932	2	123	130	122	131	114	118	120	124	136	[2]	113	[2]
24	1933	1	120	123	114	126	109	110	118	126	117	[2]	138	[2]
23	1934	0	95	130	107	116	106	106	113	118	107	110	108	110

1. Prior to 1889.
2. Fewer than 10 engineers reported.

Table XI. Comparison of Median Monthly Engineering Earnings in 1929, 1932, and 1934, of Selected Age Groups of Engineers Reporting, by Type of Education

Without regard to kind of engineering employment reported

Type of Education	Engineers Whose Age Was—														
	60 in 1929	63 in 1932	65 in 1934	52 in 1929	55 in 1932	57 in 1934	44 in 1929	47 in 1932	49 in 1934	25 in 1929	28 in 1932	30 in 1934	23½ in 1929	26½ in 1932	28½ in 1934
	Median Monthly Engineering Earnings														
Postgraduates	$484	$435	$376	$455	$421	$386	$421	$365	$339	$180	$188	$186	$145	$157	$166
Nonengineering graduates	493	400	370	482	427	387	414	384	353	166	190	197	152	149	164
First-degree engineering graduates:															
Chemical and ceramic	510	[1]	[1]	493	420	426	523	443	425	179	185	198	150	149	170
Civil, agricultural, and architectural	424	367	331	407	334	296	358	307	285	187	187	179	155	164	163
Electrical	484	415	408	438	420	379	428	353	349	167	178	180	137	152	162
Mechanical and industrial	506	416	370	483	390	346	440	351	333	180	175	180	141	152	165
Mining and metallurgical	493	420	400	437	356	340	458	374	347	183	162	183	156	149	153
College course incomplete:															
Civil, agricultural, and architectural	315	273	257	318	262	240	302	258	236	184	168	156	166	149	145
Mechanical and others[2]	420	335	300	423	333	320	401	326	301	193	174	170	178	148	153
Noncollegiate technical course:															
Civil, agricultural, and architectural	347	267	256	286	247	220	293	249	227	187	154	142	160	163	160
Mechanical and others[2]	380	300	227	402	311	297	354	289	261	186	156	159	150	150	150
Secondary-school education	360	311	283	353	311	298	308	273	252	183	168	153	160	130	134
	Per Cent of Increase or Decrease—														
	1929 to 1934	1929 to 1932	1932 to 1934	1929 to 1934	1929 to 1932	1932 to 1934	1929 to 1934	1929 to 1932	1932 to 1934	1929 to 1934	1929 to 1932	1932 to 1934	1929 to 1934	1929 to 1932	1932 to 1934
Postgraduates	−22	−10	−14	−15	− 7	− 8	−19	−13	− 7	+ 3	+ 4	− 1	+14	+ 8	+ 6
Nonengineering graduates	−25	−19	− 8	−20	−11	− 9	−15	− 7	− 8	+19	+14	+ 4	+ 8	− 2	+10
First-degree engineering graduates:															
Chemical and ceramic	[1]	[1]	[1]	−14	−15	+ 1	−19	−15	− 4	+11	+ 3	+ 7	+13	− 1	+14
Civil, agricultural, and architectural	−22	−13	−10	−27	−18	−11	−20	−14	− 7	− 4	0	− 4	+ 5	+ 6	− 1
Electrical	−16	−14	− 2	−13	− 4	−10	−18	−18	− 1	+ 8	+ 7	+ 1	+18	+11	+ 7
Mechanical and industrial	−27	−18	−11	−28	−19	−11	−24	−20	− 5	0	− 3	+ 3	+17	+ 8	+ 9
Mining and metallurgical	−19	−15	− 5	−22	−19	− 4	−24	−18	− 7	0	−11	+13	− 2	− 4	+ 3
College course incomplete:															
Civil, agricultural, and architectural	−18	−13	− 6	−25	−18	− 8	−22	−15	− 9	−15	− 9	− 7	−13	−10	− 3
Mechanical and others[2]	−29	−20	−10	−24	−21	− 4	−25	−19	− 8	−12	−10	− 2	−14	−17	+ 3
Noncollegiate technical course:															
Civil, agricultural, and architectural	−26	−23	− 4	−23	−14	−11	−23	−15	− 9	−24	−18	− 8	0	+ 2	− 2
Mechanical and others[2]	−40	−21	−24	−26	−23	− 5	−26	−18	−10	−15	−16	+ 2	0	0	0
Secondary-school education	−21	−14	− 9	−16	−12	− 4	−18	−11	− 8	−16	− 8	− 9	−16	−19	+ 3

1. Fewer than 10 engineers reported.
2. Includes chemical, ceramic, electrical, industrial, mining, and metallurgical engineers.

Thus, while the range in the median monthly earnings of the former was from $225 for first-degree electrical engineers to $250 a month for first-degree chemical and ceramic engineers, it was from $200 for engineers with secondary-school education to $229 a month for mechanical and industrial engineers with incomplete college courses in the case of the "other" engineers. Beginning at 5 years after graduation, the effect of a formal education on engineering earnings was accentuated. For example, at 11 years after graduation, the average monthly earnings of first-degree civil engineers were greater than those of the "other" engineers of this professional class. The median monthly earnings were $305 for graduates, $257 for those whose college courses were incomplete, and $254 for civil engineers who had attended noncollegiate technical schools. Similarly, in the case of first-degree electrical engineers and mechanical and industrial engineers, earnings were greater than those reported by the members of these professional classes whose college courses were incomplete or who had attended noncollegiate technical schools.[9]

It will also be noted that while mechanical engineers with incomplete college courses had the highest earnings of any of the groups of "other" engineers, their earnings differed very little from those of first-degree civil engineers. Thus, at 11 years after graduation the latter reported median earnings of $305 a month as against $319 a month for mechanical engineers with incomplete college courses. The corresponding figures at 29 years after graduation were $407 and $423 a month.

Furthermore, from 5 to 37 years after graduation, there was a fairly uniform relationship in the ranking of the earnings reported by the several types of education. Relatively, this uniformity was most marked among the "other" engineers. Thus, while secondary-school engineers remained tenth in order, civil engineers whose college courses were incomplete, or who had attended noncollegiate technical schools, held respectively eleventh and twelfth places. Over the same period, first-degree chemical and ceramic engineers were first in order. They did, however, rank tenth at 2 years after graduation. Among the remaining types of education such shifts as did occur were not very pronounced. Even in 1934, the same relative positions were maintained.

With advancing age, the 1929 data show that there was a considerable advantage in engineering earnings in favor of the graduates. Thus, between civil engineers who had

9. The term, "mechanical and all others" shown in table IX under "college course incomplete" and "noncollegiate technical schools" includes chemical and ceramic, electrical, industrial, and mining and metallurgical engineers.

first degrees and those who had incomplete college courses, the differences for men 23, 33, 43, 53, and 60 years of age were $24, $45, $55, $93, and $109 a month, while between those with first degrees and noncollegiate technical school educations, the corresponding differences were $20, $48, $65, $118, and $77 a month.

There was also a distinct variation in the earning capacities among both graduate and "other" engineers. Thus, at 10 years after graduation, the 1929 median monthly engineering earnings of graduates ranged from $290 for civil engineers to $368 for chemical and ceramic

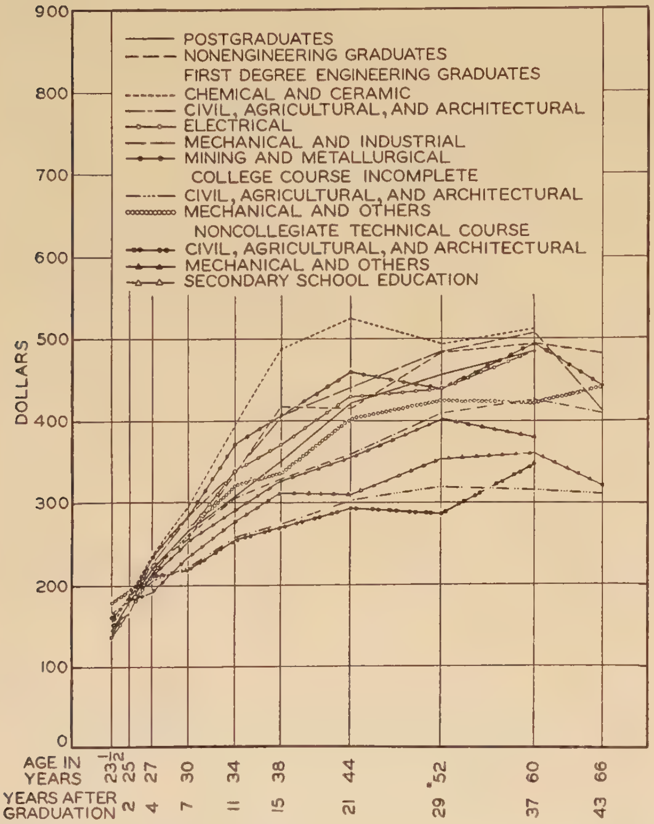


Figure 2. Comparison of medians of monthly rate of compensation according to age, 1929

Includes compensation for all kinds of engineering services reported

engineers. Graduates' median earnings 30 years after graduation ranged from $408 for civil engineers to $492 in the case of chemical and ceramic engineers. For "other" engineers, the range in earnings of men whose age corresponded to 10 years after graduation, that is, 33 years was from $242 to $300 a month, and at 53 years of age, or corresponding to 30 years after graduation, the range was from $290 to $422 a month. At both of these age points, the lowest earnings among "other" engineers were reported by noncollegiate technical-school civil engineers, the highest by mechanical and industrial engineers with incomplete college education.

A further advantage of formal engineering education was that graduate earnings from engineering work continued to increase for several years beyond the point of maximum earnings of "other" engineers. The earnings of the latter either remained stable or declined at 53 years of age.

Consideration will now be given to the effect of the depression on earnings of men with advancing years and experience and different educational backgrounds.

Over the period 1929–34, the data in table XI indicate that the graduates who were $23^1/_2$ years in 1929 and $28^1/_2$ years in 1934 received increased earnings for all kinds of engineering, except in the case of mining and metallurgical. There were, however, no increases reported by any of the "other" engineers of corresponding ages. By contrast, for the selected age groups of 52 to 57 and 44 to 49 years, decreases in earnings occurred among both graduate and "other" engineers in almost equal measure. For example, for engineers who were 44 years in 1929 and 49 in 1934, the earnings of the graduates declined from 19 to 24 per cent, while those of the "other" engineers fell by 18 to 25 per cent.

On the other hand, for men with identical years of experience, the earnings received in 1934 by both graduates and "other" engineers were all less than those which were obtained in 1929. Thus, in table XII it will be noted that at 2 years after graduation the earnings obtained for engineering services in 1934 were less than those received in 1929 by from 32 to 41 per cent for all types of education, except nonengineering graduates and those engineers with a secondary-school education. In the case of nonengineering graduates, the earnings were 24 per cent less and for engineers with secondary-school educations they were 29 per cent less.

Again it will be noted that the decreases reported by men with 5 years' experience were, in general, greater than those for men who had had but 2 years' experience and also greater than the declines in earnings reported for men with from 10 to 37 years' experience.

Table XII. Percentage Decreases in Median Monthly Engineering Earnings Over Period 1929–34 for Corresponding Years After Graduation, by Type of Education

Without regard to kind of engineering employment reported

Type of Education	Per Cent of Decrease in Earnings at Specified Years After Graduation					
	2	5	10	20	30	37
Postgraduates	32	34	24	26	21	21
Nonengineering graduates	24	33	30	[1]8	23	23
First degree engineering graduates:						
Chemical and ceramic	34	36	33	31	14	[2]
Civil, agricultural, and architectural	32	32	30	25	29	27
Electrical	34	33	31	20	18	19
Mechanical and industrial	39	35	32	[1]10	30	30
Mining and metallurgical	37	42	37	32	22	27
College course incomplete:						
Civil, agricultural, and architectural	33	30	31	26	24	21
Mechanical and others[3]	34	37	36	34	27	25
Noncollegiate technical course:						
Civil, agricultural, and architectural	41	26	31	27	23	33
Mechanical and Others[3]	36	37	34	29	31	24
Secondary-school education	29	28	34	18	23	19

1. Despite the fact that at 20 years after graduation, nonengineering graduates and mechanical and industrial engineers show only 8- and 10-per cent decreases in earnings, the consistency of the remaining decreases shown is too regular for these particular differences to have any effect on the general argument.

2. Fewer than 10 engineers reported.

3. Includes chemical, ceramic, electrical, industrial, mining, and metallurgical engineers.

Modern Trolley-Coach Operation

By EDWARD DANA

THE BOSTON Elevated Railway serves a population of about 1,531,000 people, distributed over an area of 111.56 square miles and segregated in 14 municipalities, including both towns and cities. Within its territory the railway supplies practically all of the public transportation, except taxicabs. The backbone of its system is formed by its rapid-transit division, with elevated lines, subways and some leased surface right-of-way. The rapid-transit lines are confined to Boston and Cambridge.

The territory is covered with a network of surface-car lines, with motor-bus lines and, recently, with a few trackless-trolley lines. These surface lines serve partly as feeders for the rapid transit and partly to meet local service demands.

The fare with transfers to and from the rapid-transit lines is 10 cents; that for local riding on surface lines is 5 cents. About 30 per cent of the riders pay the lower fare.

Such a unified system of local transportation as that of the Boston Elevated provides an unusual opportunity for adapting each type of service to the best advantage within certain limitations. The expensive subways and elevated structures in fixed locations, however, provide little flexibility. They are dependent largely upon the surface railways, trackless trolleys, and motor buses as feeders.

The surface railway situation in Boston is unusual, in fact is unique, in that in and even beyond the congested business section the cars run through subways and on overhead structure, which make them to this extent a part of the rapid-transit system, with which these structures connect.

While the surface subways and viaduct expedite the movement of surface cars, they also decrease the flexibility of the surface lines. It is probable that the use of subways for surface cars is a temporary expedient in urban transportation, the logical use of such expensive way and structure being for rapid transit.

The shifting demand for urban and suburban transportation in a group of communities like metropolitan Boston renders necessary a ready adaptability of services. Thus in spite of heavy investment in track and overhead construction, it has been necessary to abandon many miles of surface railway when the demand for service was greatly reduced, or when the track was wearing out and the density of traffic would not warrant rebuilding.

The motor bus and, later, the trackless trolley entered the picture at the time when something was urgently needed to meet this situation. The Boston Elevated began to use the motor bus in 1922 and in replacing uneconomical rail lines or in giving modern transportation to communities not previously adequately served increased its bus mileage from 63,959 revenue-miles in 1922 to 10,485,554 revenue-miles in 1936. At the same time the surface-car mileage fell from 37,195,035 revenue-miles in 1922 to 24,254,263 revenue-miles in 1936. The combined mileages of the 2 services show a reduction from 37,258,994 revenue-miles in 1922 to 34,739,817 in 1936, or about 6.8 per cent.

The experience of the Boston Elevated Railway with the trackless trolley has to date been on a small scale and extends back only to April 11, 1936, when a car line in Cambridge was replaced by a trackless-trolley line. Since this line was opened the weather has been favorable so that neither on it, or a line started early in 1937, has there been opportunity to observe operation under conditions such as prevailed during parts of the two preceding winters. The railway has now 49 vehicles in operation.

The Cambridge line serves the Harvard square business district, and residential and business districts of East Cambridge. The terminals are important interchange points for car lines from Boston and for local radiating car and bus lines.

The Cambridge trackless-trolley route is 2.6 miles long, one-way mileage, requires 10 trackless trolleys and furnishes a headway of 5 to 6 minutes in rush hours and 12 minutes out of the rush hours. It replaced a car line.

In another part of the elevated territory, in Malden and Everett, 3 trackless-trolley lines have been installed during 1937, all terminating at one end in the main elevated-line terminal in Everett.

One of these, the Linden line, connects the terminal with an outlying residential section of Malden, and serves also certain business sections of Everett. The Linden line is 3.6 miles long, requires normally 13 vehicles, and gives a 5 to 6-minute time in rush hours and a 15-minute normal time headway. It replaced in part a car line and in part a bus line.

The second Everett line connects the rapid-transit terminal and an important cemetery, which gives the line its name, Woodlawn. The Woodlawn line connects the business section with several residential districts. It is 2.6 miles long, partly over the Linden line route, requires 11 vehicles, and operates on a 3- to 4-minute headway in rush hours, and a 12- to 15-minute headway at other hours. This route replaced a car line.

The third Everett trackless-trolley route operates out of the rapid-transit terminal and connects it with Malden square, 3 miles away by trackless-trolley route. Part of the route is over the Linden line. Here the rush-hour headway is from 5 to 6 minutes and the normal headway is 15 minutes. Seven vehicles are required for this service. The 3 Everett lines operate from the same carhouse

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where 8 additional trackless trolleys are available as "spares."

Other lines are in the preparatory stages as this is written, all designed primarily to serve as feeders for the rail lines and to furnish attractive local service also. The fares on the lines mentioned, without transfer to the rapid-transit lines, is 5 cents. The base fare in Boston, as stated, is 10 cents. In elaboration of the above expression "in the preparatory stages," following is the procedure locally.

Trackless Trolley Lines of Boston Elevated Railway

Name of Line	Length of Route in Miles	Number of Vehicles for Regular Requirements	Spare Vehicles	Headway		Date Service Was Inaugurated
				Rush-Hour	Normal	
Harvard-Lechmere (Cambridge)	2.6	7	3	5 to 6 minutes	12 minutes	April 11, 1936
Linden-Everett Terminal (Malden and Everett)*	3.6	13	8	5 to 6 minutes	15 minutes	January 9, 1937**
Woodlawn-Everett Terminal (Everett)*	2.6	11		3 to 4 minutes	12 to 15 min.	June 19, 1937
Malden Square-Everett Terminal (Malden and Everett)*	3.0	7		5 to 6 minutes	15 minutes	September 11, 1937

* These routes overlap to some extent. Total length of street traversed, 7.8 miles

** Part of this line began operation November 28, 1936

Prior to the inauguration of a new trackless-trolley line it is necessary to secure a permit covering the route from the city and town authorities within whose jurisdiction the route will lie, together with a location for the necessary poles, wires, and other appliances and apparatus. Before the granting of such a permit, it is necessary that a public hearing be held, notice of which must be published in one or more newspapers at least 14 days prior to date set for hearing. The granting of this permit must then be approved by the State Department of Public Utilities, after advertising public hearings. After the poles and all the overhead construction have been erected and installed, it is then necessary to secure a certificate of safe operation from the Department of Public Utilities.

Trackless trolleys have practically the same status as street cars in Massachusetts and are exempt from the requirements of the motor-vehicle law. In securing the necessary legal authority incidental to the operation of trackless trolleys, the procedure followed is that contained in the law governing street-railway locations.

The adoption of a new form of transportation, even one only so moderately novel as the trackless trolley, and its integration in a composite system, cannot be decided wholly from theoretical considerations. If a transportation system were being laid out as a new proposition, there would be much more freedom than exists in a situation like that of Boston.

The management of the Boston Elevated followed with interest the experiments with the modern trackless trolley beginning in Salt Lake City, in 1928, and early made plans for trying out the vehicle locally.

Extensive experience with the motor bus had demonstrated the advantages of an independent unit for existing rail routes on which the traffic had shrunk to or below the minimum at which car service is profitable, especially where the track needed replacing. The motor bus proved useful also in feeling out the traffic possibilities of a proposed route.

The trackless trolley occupies a place between the trolley car and the bus. It is really a trolley car which does not require tracks. It operates noiselessly as contrasted with the car and without fumes as contrasted with the bus. In common with the bus and in contrast with the car it permits curb loading eliminating the risk involved in crossing traffic before boarding and after alighting.

The trackless-trolley vehicle body is limited in size by street conditions. It probably will never be possible to build this vehicle with the capacity of a car running on rails. If a large number of people require service within limited periods, large vehicles are necessary. Trolley cars on rails are best for heavy peak loads, but where they have been ruled out on the basis of investment and operating cost, the large-body trackless trolley vehicle is next best.

Early trackless-trolley bodies were kept within bus size limits; but for use in cities with wide streets, vehicles wider than the early 96 inches were found practicable. Some designs went to 106 inches. The wider bodies make wider aisles possible and decrease the time required for passengers to board and alight.

In Boston a 100-inch width is used, as the probable maximum width for local street layouts.

The permissible length depends also on street conditions, particularly at intersections. A body with seating capacity for 40 persons is a popular size, the length being say around 33 to 34 feet. This compares with a length of 6 to 8 feet less for the 30-passenger trackless trolley, also a popular size and used where traffic demands do not warrant the larger vehicle.

As far as general design, seating, lighting, and other items the trackless trolley body utilizes the progress which has been made in the development of the comfortable and attractive bus body of today.

From the operating standpoint, the high acceleration rates and smooth pick-up of the trackless trolley permit it to make good speed amid vehicular traffic. This results from the large power capacity of the vehicle, from the characteristics of the series motor, which gives maximum torque at starting, and from the ease of control of the starting current by means of rheostats graduated in small steps. With these vehicles, the driver finds himself limited as to speed by his environment rather than the capacity of his equipment.

The pedal control here, as in the gasoline motor bus, greatly facilitates smooth operation, as compared with the trolley car, besides leaving the operator's hand free for other work. The absence of gear shift and clutch in the trackless trolley accentuates this advantage.

The replacement of trolley cars by gasoline-motor buses on a large scale is a serious matter from the power standpoint to railways that generate their own power. This is

the situation in Boston, where the Railway has 2 up-to-date power plants, one having an installed generator capacity of 120,000 kilowatts, the other of 60,000 kilowatts. There is an equally modern distribution system at 13,200 volts, 3-phase, with automatic supervisory control in several substations.

The trackless trolley tends to offset this power load loss, and the low power cost under these conditions is an argument in its favor.

The trackless trolley comes into prominence at a time when its designers can profit from experience gained in the development stages of other vehicles. In an earlier era of this development, when the trackless trolley was given a fair trial on Staten Island, N. Y., in Rochester, N. Y., and elsewhere it antedated the modern motor bus. The vehicle was a small car body mounted on a truck chassis with solid rubber-tired wheels. It proved not to be a formidable competitor of street railways, partly because it had little in the way of comfort and speed to offer the passenger, and partly because the trolley car enjoyed a high degree of popularity.

Since then the modern gasoline motor bus has been evolved, a distinctive vehicle, profiting of course by the marvelous development of the automobile. The pneumatic tire must be credited with a large share in the present-day status of the motor bus, and in turn of the trackless trolley. Not only tires, but bodies, steering gear, control and braking systems form the contributions of the motor bus to trackless trolley development.

Still closer approach to the trackless trolley was the gas-electric bus, for this, among other things, forced the development of the light-weight series motor. It is a short step from the gas-electric bus to the trackless trolley, in fact in one type of trackless trolley it is no step at all, that is in the so-called "all-service" vehicle used on a large scale by the Public Service Coordinated Transport. This vehicle is driven by an electric motor which uses central power station energy where wires are available and uses a gasoline or Diesel engine to generate power where wires are not available.

The trackless trolley undoubtedly owes something also to the research work done by the American Transit Association in developing the so-called "P.C.C." (Presidents' Conference Committee) car. This research extended to all of the elements of a modern rail car, many of which are found in the trackless trolley.

While undoubtedly the trackless trolley utilized developments in other vehicles, it in its turn has furnished incentive for further development of the high-speed light-weight motor. Motors of 125 horsepower are now in use in these equipments on 40-passenger trolley coaches, with a weight per motor of not much over 1,100 pounds. The combined weight of 2 65-horsepower motors, generally used on 2-motor equipments is several hundred pounds greater. The single-motor equipment also makes possible a saving in the weight of the control apparatus.

Most of the trackless-trolley equipments recently ordered are single-motor equipments. Lower cost, less weight, and simplicity are the ruling considerations, offsetting the higher energy consumption due to necessary abandonment of the series-parallel control which is standard on all d-c traction equipment.

In some ways the use of rheostatic control in the trackless trolley seems like a technical step backward. It took a long time to develop and perfect the series-parallel method of bringing a vehicle to speed, a method which is relatively economical. On the other hand the power item is not relatively as important as it once was. Modern power plants produce electrical energy at a much lower cost than formerly, whereas other items of transportation cost have gone up.

Again, the simplicity and smoothness of the rheostatic control offsets power costs. A great deal depends upon the skill of the operator as to the waste of power in the rheostats. A new technique must be learned, to prevent unnecessary running on resistance points.

The shunted field is an important feature of the single-motor equipment, which tends to improve operating efficiency and give better speed control. The design is such as to give a better free running speed and acceleration with one motor than with 2, and to permit better schedule performance.

The advantages of the single-motor equipment are so appealing that only the lack of availability of a suitable axle delayed its adoption on the 40-passenger trackless trolleys, although it was used earlier in the 30-passenger vehicle, where a suitable axle for a single 65-horsepower motor was available.

In the past, salient obstacles to the adoption of the trackless trolley have been the necessity for using 2 trolley wires and trolley poles, and the requirement that the mounting pole be sufficiently flexible to permit curb loading and passing of other traffic. Operating and construction difficulties connected with the double trolley have been overcome and with careful design the overhead need not be unsightly. Overhead intersections and switching involve complications but improvement in line equipment has kept pace with the vehicle. The double trolley is not the bugaboo that it once was.

The suddenness with which the trackless trolley has been accepted as a piece of rolling-stock in good standing is remarkable. It was not until 1935 that the number of vehicles in use was large enough to attract much attention. From 1928 to 1935 there was an average increase around 70 vehicles per year. The next year the number nearly doubled and as this is written there are more than 1,600 vehicles in service or on order, including the "all service" vehicles of Public Service.

There appears to be a growing tendency to order trackless trolley for service of medium density where moderate headways are required, leaving the extremes in both directions for the trolley car and the motor bus, respectively.

In all communities served by a public utility the patrons and the public are impressed by indications of progressiveness on the part of the utility. The addition of the trackless trolley to older equipment has a public-relations value in this direction. In the many cities where trackless trolleys have been recently adopted, an encouraging public appreciation has rewarded the management.

Switching Surges
With Transformer Load-Ratio Control Contactors

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Introduction

THE INVESTIGATION described in this paper was undertaken to determine the magnitude and characteristics of the abnormal voltage transients accompanying the operation of load ratio control contactors on power transformers. As test results definitely established the fact that currents may be abruptly ruptured at other than normal current zero, accompanied by very severe over-voltages, the main purpose of the paper was directed to this phenomena, both from the experimental and theoretical viewpoint. It is believed that the subject will prove interesting to anyone concerned with switching surges in general, especially in view of the fact that certain aspects of the phenomena appear not to have been presented heretofore. Thus, the effect of current interruption at other than normal frequency current zero is gone into in detail; general equations on recurrent restriking are given; the extremely interesting possibility of restriking so as to practically discontinue the voltage transient is described; and the paradox of an increase in recovery voltage when shunt capacitance is increased is explained. These points are illustrated and supported by oscillographic evidence.

It should be noted, however, that in the experiments described, abrupt current rupture occurred only when values were 15 amperes or less, and were not obtained above 15 amperes. Furthermore, tests were limited to one type of circuit and to one type of switching device, namely, those used in connection with transformer tap changing equipments. Obviously the scope of the experiments is so limited that considerable caution must be used in forming general practical conclusions.

The now classical theory of circuit breaker recovery voltages, as first given by Park and Skeats[1] and subsequently extended by Boehne,[2] assumes that rupture of the current does not take place until a normal current zero.

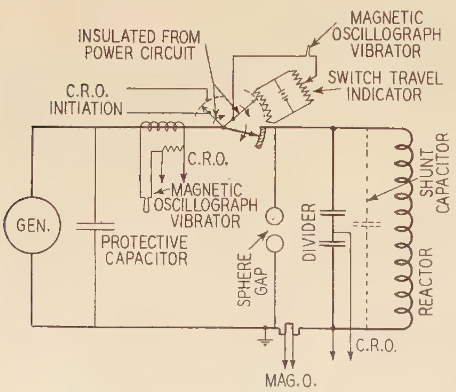

Figure 1. Single-frequency test circuit

At this instant the current permanently extinguishes and the isolated part of the circuit, comprising the inductances of apparatus and the (small) capacitances of windings, bus bars, etc., undergoes a local oscillation. In a single frequency local circuit of this nature the oscillation results because the circuit capacitance is charged to the circuit voltage prevailing at the instant of normal current zero, and for a completely reactive circuit this is the normal

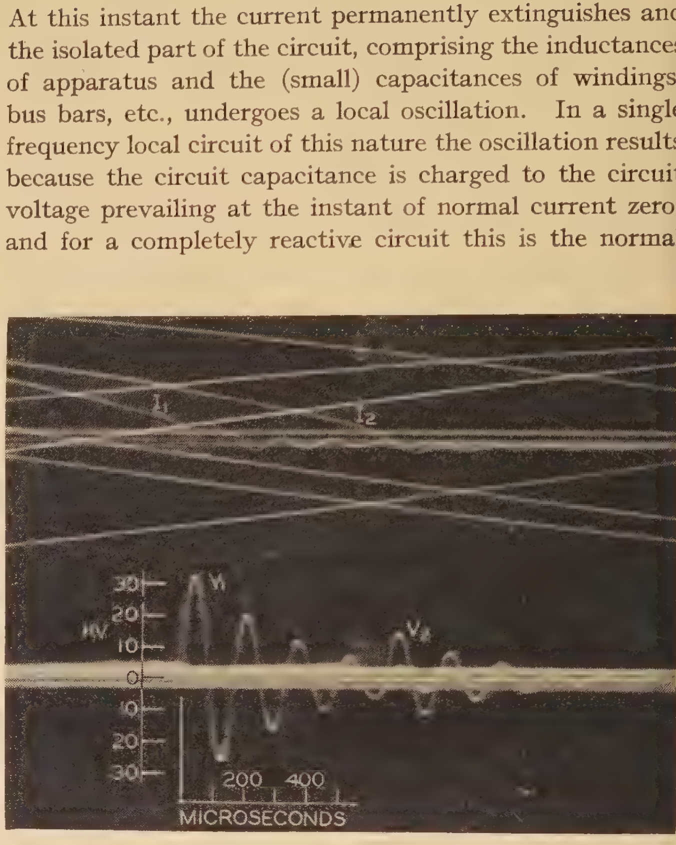

Figure 2. Cathode-ray oscillograms of 2 switching transients

frequency peak recovery voltage. It follows, then, that the transient oscillation has a maximum value not exceeding normal frequency peak recovery voltage; and the total voltage across the switch contacts, being the sum of the high frequency oscillation and the normal frequency voltage, cannot exceed double normal frequency recovery voltage, actually less on account of the decrements.

All of this has led to considerable speculation concerning the question: do currents extinguish precisely at a normal current zero?

Current Interruption

A switch will endeavor to open the circuit at the instant when the contacts begin to part, but an arc forms and

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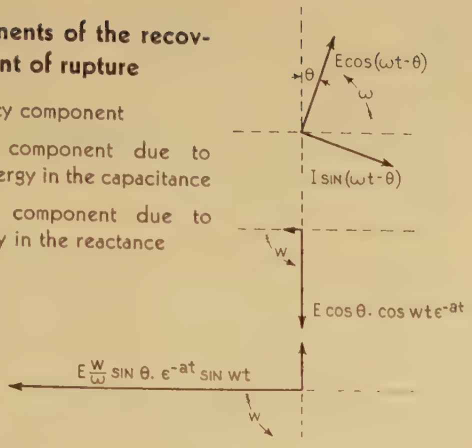
1. For all numbered references, see list at end of paper.

Figure 3. Components of the recovery voltage at instant of rupture

(*A*)—Normal-frequency component

(*B*)—High-frequency component due to stored electrostatic energy in the capacitance

(*C*)—High-frequency component due to stored magnetic energy in the reactance



maintains the circuit until it is disrupted by the surrounding dielectric. Ordinarily, this occurs so close to a normal current zero that it appears on the oscillograms as interruption at a current zero. In order to examine the exact instant of rupture in more detail, records were taken with the 3-element cathode-ray oscillograph developed by E. J. Wade.[3] A single cycle of normal frequency was drawn out so as to occupy the whole length of the film (24 inches) but of only half an inch amplitude; so that the point of rupture was very distinct. It was found that the contactor could abruptly interrupt the current at values of the order of 5 amperes, which in these tests corresponded to cut-off some 10 degrees from a normal current zero. Two examples are given in figure 2*a*. The ensuing high-frequency oscillations in the current waves through the reactor are clearly shown, and in figure 2*b* the corresponding high-frequency recovery voltages. The circuit consisted of a reactor of 0.25 henry inductance shunted by a capacitance of 0.003 microfarad. The natural frequency of the circuit was thus

$$f_n = \frac{1}{2\pi\sqrt{LC}} = \frac{1{,}000}{2\pi\sqrt{0.25 \times 0.003}} = 5{,}800 \text{ cycles per second}$$

or about 100 times normal frequency. In appendix I it is shown, on the assumption of abrupt current interruption that the recovery voltage is approximately:

$$e \cong E\left[\cos(\omega t - \theta) - \left(\cos\theta + \frac{a}{\omega}\sin\theta\right)\epsilon^{-at}\cos wt - \frac{w}{\omega}\sin\theta\epsilon^{-at}\sin wt\right]$$

in which $E\cos(\omega t - \theta)$ is the normal frequency voltage, θ the angle from a current zero at which interruption occurs, $(w/2\pi)$ the natural frequency, and a the decrement factor. There are 2 components to the high-frequency oscillation. The cos wt term is that present when interruption occurs at a normal current zero, $\theta = 0$, for then

$$e = E[\cos\omega t - \epsilon^{-at}\cos wt]$$

$$\cong E(1 - \cos wt)$$

for short times and no decrement. This is the recovery voltage of the prevailing theory[1] and is seen not to exceed twice normal peak voltage.

The sin wt term exists only for finite values of θ, but since w/ω is usually quite high (100:1 in figure 2) it is clear that even a very small value of θ will result in high voltages. It is this term which is responsible for the excessive voltages experienced during switching. It is:

$$E\frac{w}{\omega}\sin\theta = E\frac{(\text{natural frequency})}{(\text{applied frequency})} \times \frac{(\text{cut-off current})}{(\text{normal crest current})}$$

$$= \sqrt{\frac{L}{C}}\,(\text{cut-off current})$$

This equation shows that:

(a). The higher the natural frequency the higher the voltage, hence the voltage increases inversely as the square root of the capacitance. (It will be shown later that this is not necessarily true if restriking occurs.)

(b). The voltage is directly proportional to the cut-off current. This cut-off current is probably a function of the switch speed, type of switch, and other factors.

Thus, if no restriking occurs, the recovery voltage consists essentially of 3 terms:

$$e = \overset{I}{\left\{\begin{array}{l}\text{normal}\\\text{frequency}\\\text{recovery}\\\text{voltage}\end{array}\right\}} + \overset{II}{\left\{\begin{array}{l}\text{high-frequency}\\\text{term depending}\\\text{upon the capaci-}\\\text{tor voltage at}\\\text{instant of cut-off}\end{array}\right\}} + \overset{III}{\left\{\begin{array}{l}\text{high-frequency}\\\text{term depending}\\\text{upon the reactor}\\\text{current at instant}\\\text{of cut-off}\end{array}\right\}}$$

of which the last is by far the most important. These components are shown as vectors in figure 3.

Since, however, the tendency is to rupture very close to a normal current zero, the probability of large cut-off currents, and correspondingly high voltages, is not great. The following results, obtained by E. A. Elge, from sphere gap measurements on a 0.25-henry reactor shunted by a 0.0003-microfarad capacitance, give the number of switch operations which were necessary to cause gap sparkover. It will be noted that the probability of voltages greater than 7 times normal is very much less than for the small voltages.

Arc Voltage

The actual mechanism of current interruption by any switch must involve some sort of a rapidly increasing arc drop which breaks the circuit when the resulting transient switch current passes through zero. Mr. C. Concordia, in

Table I

Gap Setting, Kv (Rms)	Times Normal Voltage	Switching Operations to Cause Gap Sparkover
3.0	1.5	1
5.25	2.62	3
6.0	3.0	3
7.0	3.5	1
10	5	4
12	6	6
14	7	23
16	8	42
18	9	69
20	10	27
22	11	112
24	12	25
26	13	None in 75
36	18	6
40	20	None in 50

an unpublished report, has calculated the recovery voltage assuming the arc drop to increase linearly as a function of time, and under this assumption finds that for slow rates of increase of the arc drop the recovery voltage tends to become independent of the circuit constants, while for fast rates it tends to become independent of the switch characteristics. But the oscillograms of the present investigation show the rupture sufficiently abrupt with respect to the natural periods, so that for all practical purposes it is sufficient to regard the current interruption as instantaneous. The current cut-off is equivalent to the application of a steep wave front. It is well known that a wave front even as long as 25 per cent of the natural period will succeed in developing at least 90 per cent of the oscillation that a rectangular wave front could develop (see, for example, figure 113 of reference 4). For circuits with much higher natural frequencies than those with which this investigation is concerned, it may be expedient to consider more carefully the arc characteristics. The abruptness of the cut-off is clearly shown on the oscillogram of figure 4 for the interruption of a d-c current.

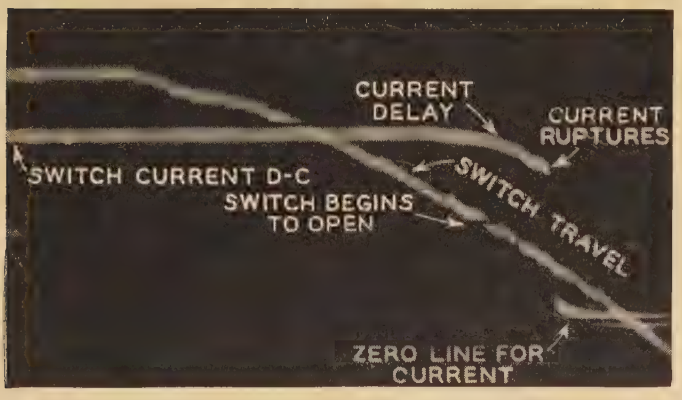


Figure 4. Oscillogram of a d-c current interruption and switch travel

Restriking

When the switch arc extinguishes the first time, a high-frequency oscillation is initiated. This transient starts with the current in the reactor and the voltage across the capacitor at the instant of rupture as initial values, and if not interfered with, the transient develops as previously described. As the transient voltage increases, the switch contacts are opening, thus increasing the dielectric recovery strength of the switch. If the transient voltage overtakes the dielectric recovery, the arc will restrike, and the switch then makes a second attempt to open the circuit. At this second attempt the recovery voltage transient is very similar to that following the first attempt, except that the amplitude of the oscillation is reduced. In the meantime the switch has been continuously opening, acquiring greater dielectric strength, and therefore it will be a longer time before the arc again restrikes, if at all. Thus current interruption is a race between the rate of increase of dielectric strength and the rate of rise of the recovery voltage, and restriking gives the switch time to open.

The general equations of the restriking phenomena are given in appendix II. The principal term in the voltage transient following the k'th restrike is:

$$\bar{e} \cong -wLI_k\epsilon^{-a(t-t_k)}\sin w(t - t_k)$$

in which I_k is the initial current in the reactor at the start of the k'th restrike and lags the voltage by approximately 90 degrees, and t_k is the instant at which this restrike occurs, counting time from the initial current rupture. The vector diagram of the successive restriking, taking cognizance of the above term only, is shown in figure 5A, the instantaneous values being the projections on the vertical axis. The sequence of events is as follows: at $t_0=0$ the switch ruptures the circuit for the first time and the voltage vector

$$e = -wLI_0\epsilon^{-at}\sin wt$$

begins to revolve at the high frequency angular velocity w, and to shrink exponentially. At time t_1 when the instantaneous voltage is e_1 the voltage is sufficient to break down the dielectric of the switch and the first restrike occurs. The current in the reactor at this instant is

$$I_1 = I_0\epsilon^{-at_1}\cos wt_1$$

and the new voltage transient is

$$e = -wLI_0\cos wt_1\epsilon^{-at}\sin w(t - t_1)$$

or the previous transient reduced by $\cos wt_1$ and starting at time t_1. By the same reasoning the voltage following the second restrike is

$$e = -wLI_0\cos wt_1\cos w(t_2 - t_1)\epsilon^{-at}\sin w(t - t_2)$$

Successive restriking of this nature continues to take place until the dielectric strength of the switch has increased to a value such that the transient voltage is unable to break it down. Thereafter the transient voltage is simply a damped oscillation, shown in figure 5 as a logarithmic spiral.

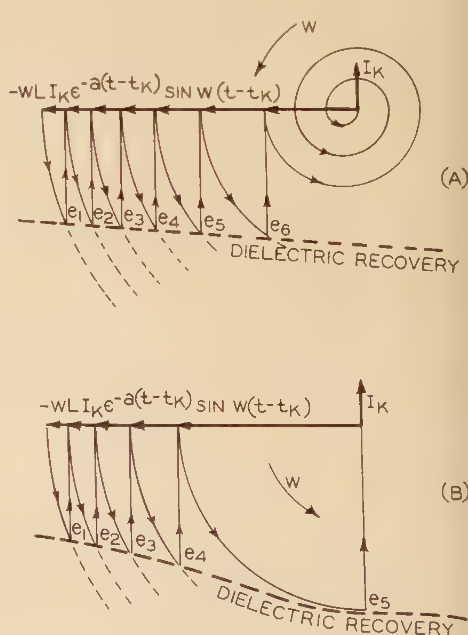


Figure 5. Vector relationships in restriking phenomena

(A)—Successive restriking with a final oscillation

(B)—Successive restriking without a final oscillation

If, now, the last restrike occurs at the crest of the oscillation, as shown in figure 5*B*, the current is zero, and there will be no damped oscillation associated with the electromagnetic energy, although an oscillation will exist due to the electrostatic energy which has been neglected in the foregoing.

Effect of Dielectric Recovery Rate

In figure 6 the dielectric recovery is shown as a straight line starting at the same initial value, but with 4 different slopes, or rates. Only part of the first half cycle of each oscillation of voltage is shown. Actually, the transient is a damped oscillation about the time axis. In figure 6*a* the dielectric recovery (*d.r.*) is so fast that the oscillation reaches crest without restriking, and the recovery voltage (*r.v.*) is the maximum possible for a given angle of rupture θ. If, now, the *d.r.* is slowed down, as in 6*B*, the rising *r.v.* meets the *d.r.* at point *a*, and then restrikes instead of rising on to the previous crest V_1, and the second attempt carries the crest to some value V_2', less than V_1. In 6*c* the *d.r.* has been reduced so as to involve 2 restrikes, while in 6*D* it has been reduced to show 3 restrikes, and $V_4''' < V_3''' < V_2''' < V_1'''$.

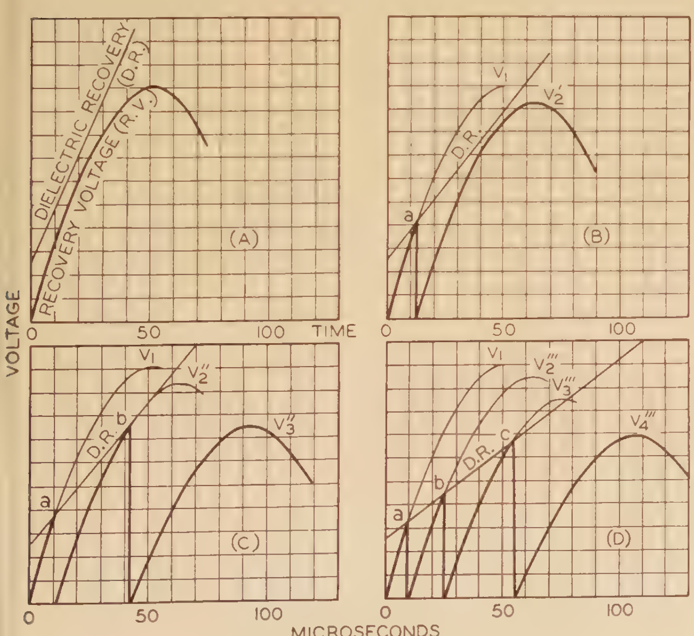


Figure 6. Effect of dielectric recovery rate

Initial angle of rupture—θ = 4 degrees
Natural period—T = 200 microseconds

Effect of Initial Angle of Rupture

As previously discussed, for an unhindered oscillation the amplitude of the *r.v.* is directly proportional to the cut-off current, that is proportional to sin θ where θ is the angle from a current zero at which the switch makes its first attempt to open the circuit. But if restriking occurs this is not true. Figure 7 illustrates the effect of the cut-off angle θ when restriking occurs, the *d.r.* being the same for all angles. In 7*A* where θ = 4 degrees, 3 restrikes occur in succession before the *d.r.* finally escapes the *r.v.* In 7*B* the angle is θ = 3 degrees, and only one restrike occurs, and on this account V_2' is very little less than V_4, although $V_1' = 0.75\ V_1$. In 7*C* at θ = 2 degrees there is no restriking and $V_1'' = 0.5\ V_1$. A further reduction to θ = 1 degree reduces the *r.v.* to $V_1''' = 0.25\ V_1$.

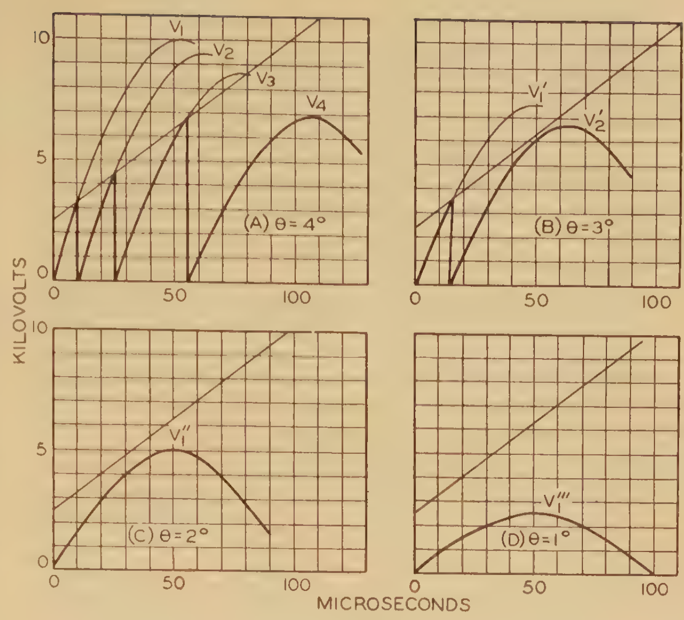


Figure 7. Effect of initial angle of rupture

Natural period—T = 200 microseconds

Effect of Capacitance

When restriking occurs, it is quite possible to obtain higher *r.v.* by adding capacitance, which is quite contrary to the case when no restriking occurs. The addition of capacitance does 2 things: (1) it reduces the amplitudes proportional to $1/\sqrt{C}$; and (2) it increases the natural period proportional to $\sqrt{C}$. Therefore, as shown in figure 8, it may be that the number of restrikes can be reduced if the natural period is increased, and on this account a higher voltage produced than would result with more restrikes at a smaller capacitance. Thus in 8*A* 3 restrikes occur before the oscillation develops with a crest of V_4 = 70 per cent. Increasing the capacitance by 35 per cent as in 8*B* increases the natural period just enough to permit only one restrike, and the resulting crest voltage V_2 = 76 per cent; while in 8*C*, where the capacitance has been doubled, restriking is avoided entirely and the *r.v.* crest is V_1 = 72 per cent. A further increase in capacitance, as in 8*D*, can only result in a reduction of *r.v.* crest, in this case to V_1 = 57 per cent.

Oscillographic Evidence

Effect of Capacitance

The foregoing effects are well illustrated by the reactor voltage oscillograms of figure 9. In 9*A* the shunt capacitance was only 0.004 microfarad and the natural period 93 microseconds. A few restrikes are discernible at the beginning of the transient, near the crest of the normal frequency voltage. Normal voltage was 1,400 volts (crest), and the transient carried to 3.5 times normal.

For $9B$ the capacitance was 0.25 microfarad and the natural period 1,360 microseconds. This oscillogram exhibits a single restrike. The voltage is materially less than in $9A$ on account of the great increase in capacitance.

For $9C$ the capacitance was 0.5 microfarad and the natural period 960 microseconds. The transient was too slow and of too low amplitude to permit restriking.

Dielectric Recovery

In figures 6, 7, and 8 the dielectric recovery was shown as a straight line starting at a finite value. Actually, this recovery must start at zero, and apparently at first increases very rapidly and then at a more uniform rate. But it must not be supposed that the *d.r.* is always at a uniform rate. The envelope of the restrike is, in fact, the curve of dielectric recovery against time; for such a curve gives the breakdown voltages at various instants. When matched with a record of the switch travel against time it is possible to correlate the *d.r.* with the switch opening. Records of this nature were taken as shown in the magnetic oscillogram of figure 4.

The erratic nature of some of the dielectric recoveries is illustrated by the oscillograms of figure 10. Thus in $10A$ 3 small restrikes are followed by a larger restrike, then another small one, and then a very pronounced final restrike, after which the switch succeeds in opening, and the circuit enters into its oscillation. In $10B$ the restriking repeats many times at essentially the same voltage before the switch suddenly becomes deionized and recovers. In $10C$ the restriking sequence starts to build up, but suffers a bad relapse lasting over many small restrikes before the circuit opens. In $10D$ a single restrike is followed by a half cycle of high-frequency oscillation, and then restriking occurs twice at the opposite polarity.

The envelope of restrikes has been plotted for most of the 74 oscillograms taken, and representative curves shown

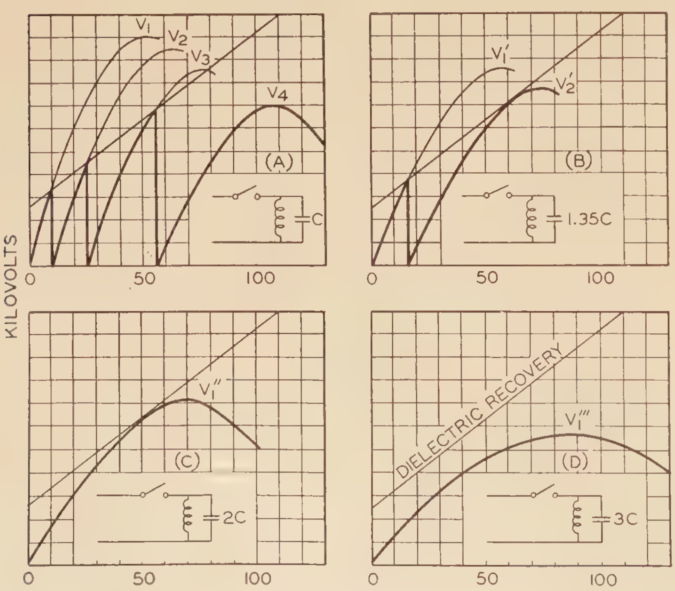


Figure 8. Effect of shunt capacitance

Initial angle of rupture—θ = 4 degrees
Natural period with C— T= 200 microseconds

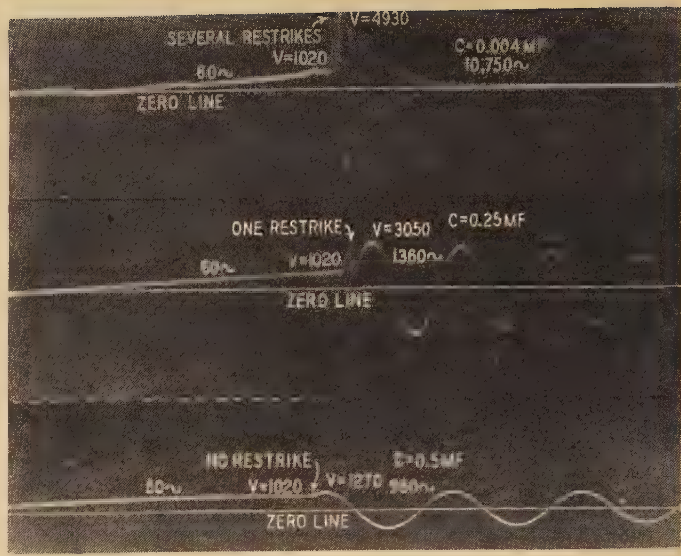


Figure 9. Effect of capacitance

Top—C = 0.004 microfarad, several restrikes
Middle—C = 0.25 microfarad, one restrike
Bottom—C = 0.5 microfarad, no restrikes

in figure 11. It is seen that the dielectric recovery is very erratic for this type of switch.

Vanishing of the Oscillations

The higher up on the oscillation at which restrike occurs, other things being the same, the smaller the amplitude of the subsequent oscillation, and restrike on the crest practically discontinues the transient. The appropriate equations are given in appendix II, and the physical reason, as previously discussed, is simply that restrike at the crest of the voltage oscillation corresponds to zero current in the reactor, while immediately following restrike the voltage to which the capacitance is charged is the normal frequency voltage, so that the only energy supporting the subsequent oscillation is that of the capacitance charged to normal voltage.

This effect is illustrated in figure 12. These oscillograms are for a 125-volt d-c circuit, and as seen, the transient voltage at about 22 degrees results in a voltage of 8,400 volts (67 times normal). In $12B$ the restrike occurs at about 78 degrees and this is so close to a voltage peak that the subsequent oscillation is greatly reduced. In $12C$ and $12D$ the restrike occurs on the crest of the oscillation at about 90 degrees and the subsequent oscillation is barely discernible on the oscillograms. This small oscillation is really of normal voltage amplitude, but appears insignificant compared with the high transient voltage peaks.

Shunt Resistors

The provision of a shunt resistor offers a parallel path for the reactor current after the switch has opened, and thereby limits the recovery voltage. There is a critical value of resistance $r = 0.5\sqrt{L/C}$ which suppresses the oscillations. In figure $13B$ is shown the effect of shunting a circuit of $L = 0.055$ and $C = 0.001$ with a resistance of

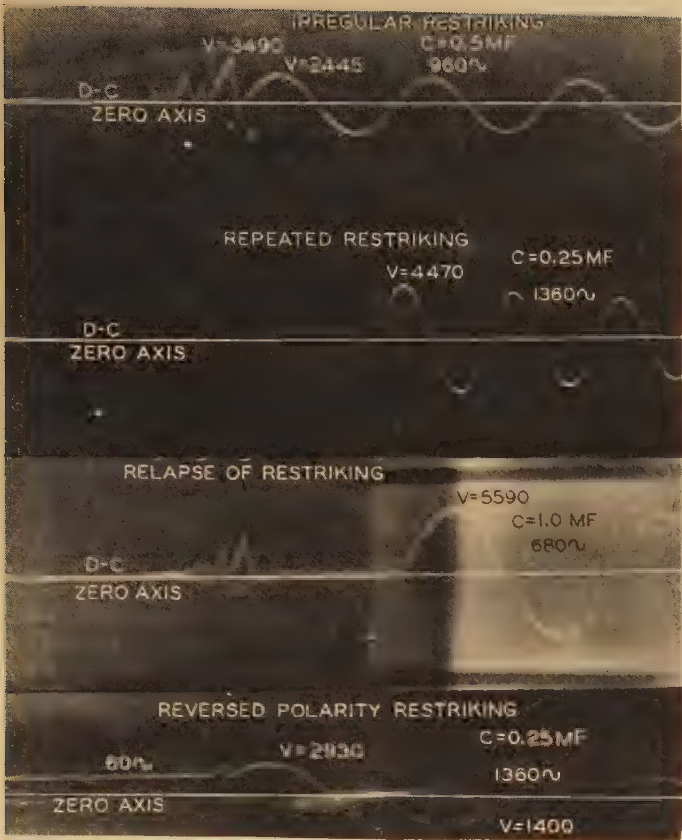


Figure 10. Erratic nature of restriking

5,000 ohms. The critical resistance in this case is r = 3,700 ohms, so that there is still a tendency to oscillate with 5,000 ohms.

Figure 13*C* shows the effect of a Thyrite shunt. Since this material has a resistance characteristic which is low for high voltages and high for low voltages, it is to be expected that when used as a shunt resistor the higher voltages will be prohibited, but free oscillation can develop at reduced voltage. The oscillogram of 13*B* confirms this.

The result of a step-by-step calculation, according to appendix II, is shown in figure 14. This shows that with an appropriate Thyrite shunt there is no excessive voltage across the switch contact, and the transient is a smooth curve free of oscillations. The Thyrite shunt not only limits the recovery voltage, but also substantially reduces the rate-of-rise, thereby lessening the duty on the breaker.

Tests

The special testing technique for this investigation was worked out and supervised by E. J. Wade, and it was only through the use of his 3-element cathode-ray oscillograph[3] that suitable data were obtained. Preliminary tests were conducted by E. A. Elge, of which figure 2 is a sample. A total of some 250 oscillograms, both magnetic and cathode ray, were secured; and these cover 2 different reactors, 6 different shunt capacitances, constant and Thyrite shunt resistors, 2 different load ratio control switches, and both a-c and d-c switching.

A photograph of the standard *LR*-17 switch used in these tests is shown in figure 15. This switch is comparatively "fast," having a total switching time of 0.007 second, and an initial rate of opening of 0.004 millimeter per microsecond. For comparison, a *LR*-28 switch having a switching time of 0.020 second, and an initial rate of opening of 0.0015 millimeter per microsecond was also tried.

The test circuit is shown in figure 1, the essential elements being in heavy lines and the recording and auxiliary elements in light lines. The inductance for most of the tests was an oil-filled commercial reactor rated *OT*-60-369-1590-77.4, for load-ratio control, and had an inductance of 0.0055 henry. The capacitance varied from the 0.002 microfarad of the cathode ray oscillograph divider to shunts of 1.0 microfarad. The power supplies consisted of a 1,000-volt 20-ampere a-c source, and a 125-volt 25-ampere d-c source. To protect these sources from excessive switching surge voltages, and also to simulate an "infinite bus," a large protective capacitor of 0.5 microfarad was across the power supply but on the line side of the switch. The transient voltage across the reactor was recorded by one of the tubes of the 3-element cathode-ray oscillograph, through the capacitance divider.

A current transformer with a resistor across its secondary was intended to yield both cathode ray and magnetic oscillograms of the switch current. But these proved disappointing, as the flux trapped in the core of the current transformer, upon interruption of the current through the switch, decayed exponentially through the resistor and gave an entirely erroneous picture of the current cut-off. This was confirmed by changing the value of the resistor,

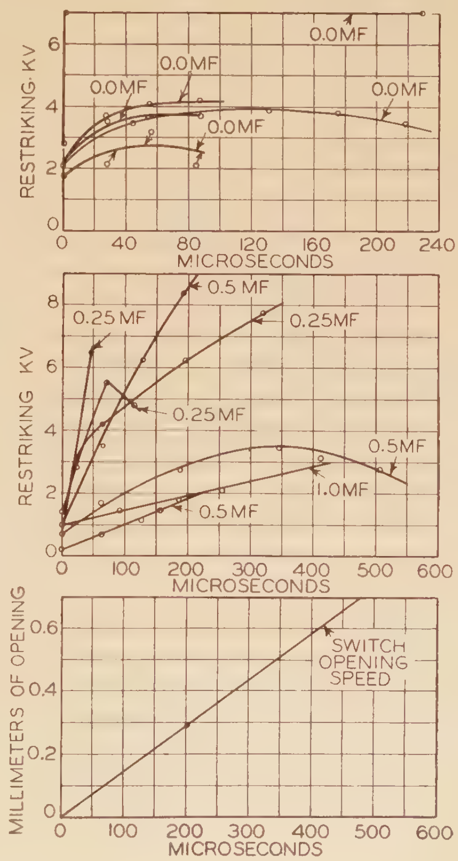


Figure 11. Dielectric recovery

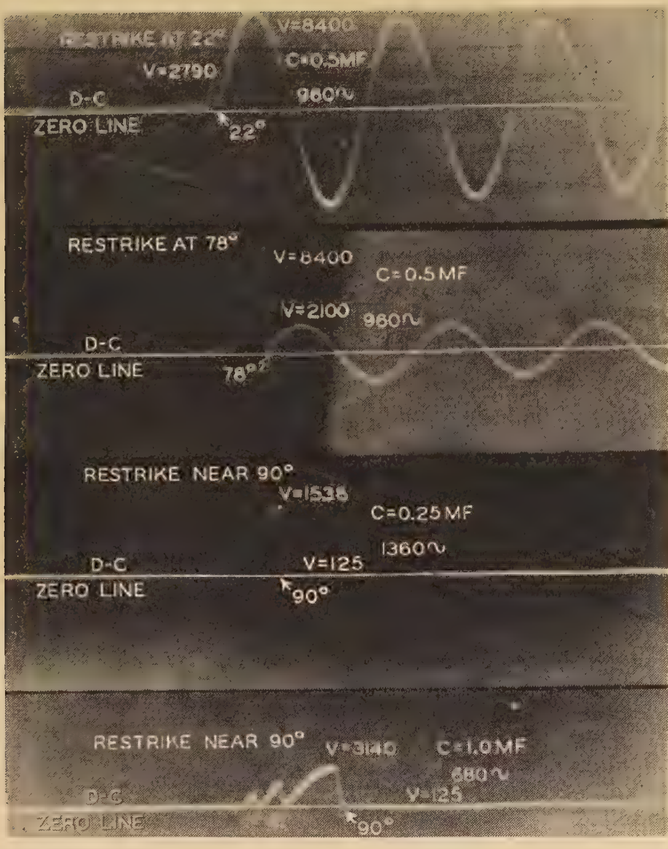


Figure 12. Effect of the point on the high-frequency oscillation at which restrike occurs (d-c switching)

which changed the time constant of the exponential decay. In addition, this current transformer broke down sometime during the tests and was defective for an unknown period. Magnetic oscillograms of the circuit were also obtained from a series resistor. These, however, did not show the point of current cut-off sufficiently distinctly to be of much use.

A sphere gap gave verification of the order of magnitude of the overvoltages. Since the voltage for a given circuit depends upon the intial angle of current rupture and on the number of restrikes, it was necessary to make successively more switching operations for each higher gap setting in order to be sure that the highest possible voltages were obtained.

The switch travel indicator for recording the rate of opening of the switch contacts was merely an auxiliary arm attached to the switch and arranged to move over an excited resistor as shown in figure 1. The vibrator of the magnetic oscillograph was connected between the switch auxiliary arm and a point on a potentiometer which was adjusted so as to give zero vibrator deflection just as the switch contacts began to part. A typical record is shown in figure 4. The total switch travel from the instant when its motion is initiated until it is completed is roughly a half cycle of a cosine curve (cos at), but over the range from the instant when the contacts begin to open until the current is finally interrupted, the switch travel is essentially at constant speed.

The control circuit of figure 16 was devised, so that the pressing of a button started in proper sequence the driving motors of the switch and of the magnetic oscillograph. A second auxiliary arm on the switch was arranged to initiate the cathode-ray oscillograph by making a contact prior to the opening of the switch.

All of the oscillograms were analyzed by W. D. Whinery, Jr., and the magnitudes, frequencies, number of restrikes, restriking peaks, and other pertinent information tabulated. The examples given in the paper are typical and were selected with a view to illustrating the various characteristics of the phenomena.

Conclusions

This study has shown that, for the types of circuit and switches employed, switching surges may be characterized as follows:

1. The dielectric recovery strength of the switch was very erratic, and no correlation has been found with the factors involved. A 3-to-1 increase in switch speed did not make any material difference in the recovery rate.

2. The current interruption by the switch usually occurred at or very close to a normal-frequency current zero, but rupture at other than current zero was by no means uncommon. Apparently the current cut-off was sufficiently abrupt so that for all practical purposes it may be regarded as instantaneous. The highest a-c cut-off current observed was about 5 amperes at 10 degrees from a current zero. This, incidentally, is the order of current snapping which sometimes occurs in mercury-arc rectifiers. D-c currents were abruptly interrupted at about 20 amperes.

3. If no restriking occurs, the recovery voltage consists essentially of 3 terms:

$$e = \left\{\begin{matrix}\text{normal}\\ \text{frequency}\\ \text{recovery}\\ \text{voltage}\end{matrix}\right\} + \left\{\begin{matrix}\text{high frequency}\\ \text{term depending}\\ \text{on the voltage at}\\ \text{instant of current}\\ \text{current cut-off}\end{matrix}\right\} + \left\{\begin{matrix}\text{high frequency}\\ \text{term depending}\\ \text{on magnitude of}\\ \text{of the cut-off}\\ \text{current}\end{matrix}\right\}$$

The first term is, of course, normal voltage. The second term is a maximum for current interruption at a normal current zero, for the voltage to which the capacitance is charged is then a maximum. But this term never exceeds normal voltage. It is the third term

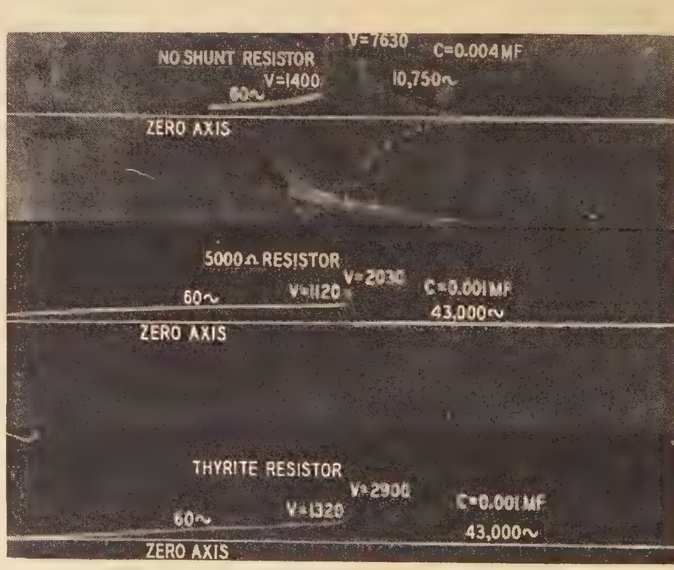


Figure 13. Effect of shunt resistor

which is responsible for the really high voltages. It represents the stored magnetic energy in the reactance, and is therefore greater the greater the current in the reactor at the instant of cut-off. Thus the further away from a current zero that rupture occurs, the higher the recovery voltage. The 2 high-frequency terms are in time quadrature and therefore do not add directly. Overvoltages of 18 times normal were obtained with a-c switching and 72 times normal with d-c switching.

4. Successive restriking was found to be the most influential factor of the recovery characteristic. Restriking was so abrupt as to be practically instantaneous and was followed by an immediate dielectric recovery.

5. The amplitude of the oscillation following the final restrike depends upon the point on the preceding oscillation at which restrike occurs, and if this happens near the crest, the transient can be reduced to normal voltage amplitude. A succession of restrikes reaching ultimate values many times normal, and then suddenly terminating in a very trivial oscillation, present a rather uncanny appearance on the oscillograms, but are simply explained and easy to calculate.

6. The addition of shunt capacitance will always decrease the recovery voltage crests if there is no restriking, but if restriking occurs it is possible to get higher voltages by adding capacitance; because the capacitance decreases the frequency to the same extent that it decreases the amplitude, and this may allow the switch to finally open with fewer restrikes.

7. A shunt resistor can be chosen which will suppress the transient recovery voltage to any desired extent. This resistor may be either constant or of such a material as Thyrite. A Thyrite resistor not only suppresses the overvoltage, but also reduces the rate of rise.

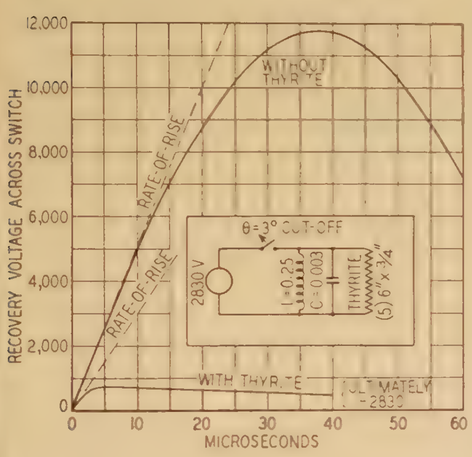


Figure 14. Effect of Thyrite shunt on recovery voltage (calculated)

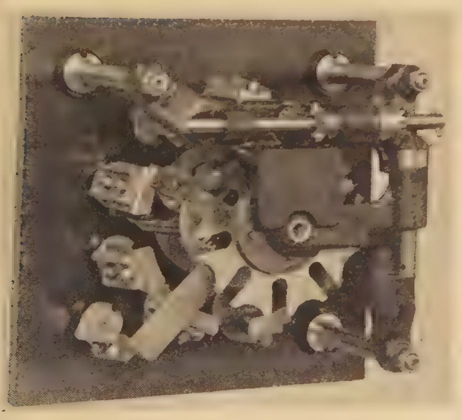


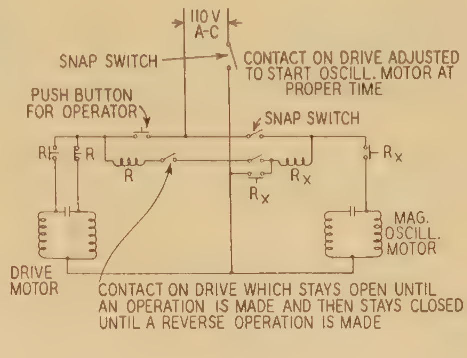
Figure 15. Load-ratio control switch used in tests

Appendix I

Finite Current Cut-Off

This appendix describes the modification necessary in the conventional theory to account for the great amplitude of the high frequency oscillation in the recovery voltage. Referring to figure 17 there is shown a generator supplying current to a reactor L having series resistance R, and shunted by a capacitance C and a leakage

Figure 16. Control circuit



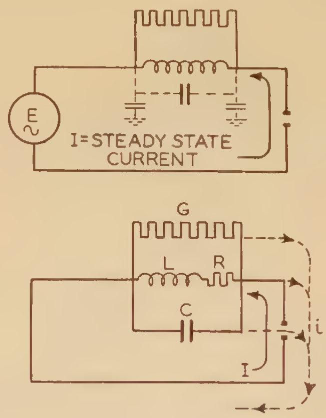


Figure 17. The elementary circuit

(A)—Actual circuit

(B)—Equivalent electric circuit

conductance G. The series resistance R, under high frequency conditions, will be many times the steady state d-c resistance of the winding. The capacitance C is the effective circuit capacitance including the series and shunt capacitance of the reactor winding, leads, etc. It is of the order of 0.001 microfarad, unless extra capacitance in the form of an actual capacitor is deliberately added. It may be remarked here, that the smaller the inherent capacitance of the circuit, the more important it is; because the amplitude of the high-frequency recovery voltage is almost inversely proportional to the square root of the circuit capacitance. The leakage conductance G is rather indefinite, unless a shunt resistor is connected across the reactor terminals. It will be shown that the high-frequency oscillation can be wiped out by a resistor of a few thousand ohms.

The conventional mathematical device for calculating recovery voltages (across the breaker terminals) as introduced by R. H. Park and W. F. Skeats,[1] consists in superposing an equal but opposite current through the breaker contacts at the instant of rupture. Thereafter, this superposed current cancels the steady state current through the breaker, and since there was no voltage across the breaker (the contacts being closed) associated with the steady state current, the "recovery voltage" must be due entirely to the superposed current. If, now, we assume the current to rupture at an angle θ prior to a current zero, the superposed current is, in operational form:

$$i = I \sin(\omega t - \theta) = I \frac{p\omega \cos\theta - p^2 \sin\theta}{p^2 + \omega^2} \qquad (1)$$

The operational impedance of the circuit, as viewed from the breaker contacts, is

$$Z(p) = \frac{R + pL}{LCp^2 + (LG + RC)p + (RG + 1)} \tag{2}$$

The operational equation for the recovery voltage then is

$$e = Z(p) \cdot i = \frac{I}{C} \frac{p(p + b)(\omega \cos \theta - p \sin \theta)}{(p^2 + \omega^2)(p^2 + 2ap + A^2)} \tag{3}$$

in which

$$a = \frac{1}{2}\left(\frac{G}{C} + \frac{R}{L}\right) \qquad b = \frac{R}{L} \qquad A^2 = \frac{RG + 1}{LC} \tag{4}$$

The solution of 3 is easily effected by the expansion theorem, and is

$$e = \frac{\omega I}{Cw^2} \left\{ \sqrt{\frac{(1 + b^2/\omega^2)}{(1 + a^2/w^2 - \omega^2/w^2)^2 + 4a^2\omega^2/w^4}} \times \sin(\omega t - \theta + \phi_1 - \phi_2) + \right.$$
$$\left. \sqrt{\frac{\left[1 + \left(\frac{b - a}{w}\right)^2\right]\left[\left(\cos \theta + \frac{a}{\omega} \sin \theta\right)^2 + \left(\frac{w}{\omega} \sin \theta\right)^2\right]}{(1 - a^2/w^2 - \omega^2/w^2)^2 + 4a^2/w^2}} \times \epsilon^{-at} \sin (wt + \phi_3 - \phi_4 + \phi_5) \right\} \tag{5}$$

where

$$w^2 = A^2 - a^2$$
$$\phi_1 = \tan^{-1}(\omega/b)$$
$$\phi_2 = \tan^{-1}\left(\frac{2a\omega}{a^2 - \omega^2 + w^2}\right)$$
$$\phi_3 = \tan^{-1}\left(\frac{w}{b - a}\right)$$
$$\phi_4 = \tan^{-1}\left(\frac{w \sin \theta}{\omega \cos \theta + a \sin \theta}\right)$$
$$\phi_5 = \tan^{-1}\left(\frac{2aw}{a^2 + \omega^2 - w^2}\right)$$

If, as would normally be the case, w is large compared with a, b, and ω, and ω is large compared to b, there is approximately $\phi_1 \cong 90$ degrees, $\phi_2 \cong 0$ degrees, $\phi_3 \cong 90$ degrees, $\phi_5 \cong 180$ degrees, $w^2 \cong 1/LC$ and 5 becomes

$$e \cong E\left\{ \cos (\omega t - \theta) - \sqrt{\left(\cos \theta + \frac{a}{\omega} \sin \theta\right)^2 + \left(\frac{w}{\omega} \sin \theta\right)^2} \times \epsilon^{-at} \cos (wt - \phi_4) \right\} \tag{6}$$

where $E = \sqrt{R^2 + \omega^2 L^2}\ I$ = normal voltage

Rupture at "Current Zero"

Putting $\theta = 0$, then $\phi_4 = 0$ and 6 yields

$$e = E(\cos \omega t - \epsilon^{-at} \cos wt) \tag{7}$$

and it is usually assumed that the decrement is negligible. Then there is the usual formula

$$e = E (\cos \omega t - \cos wt)$$
$$\cong E (1 - \cos wt) \text{ for short times} \tag{8}$$

According to this, the recovery voltage consists of a simple oscillation about normal voltage as an axis, and the amplitude of the oscillation is the same as normal voltage.

Rupture at Finite Current

Unless a shunt resistor has been added, G will be so small that the approximation 6 holds, and it may be expanded into the form

$$e = E \left\{ \cos (\omega t - \theta) - \left(\cos \theta + \frac{a}{\omega} \sin \theta\right) \epsilon^{-at} \cos wt - \left(\frac{w}{\omega} \sin \theta\right) \epsilon^{-at} \sin wt \right\} \tag{9}$$

and the last term is responsible for the very high voltages experienced. It is

$$E \frac{w}{\omega} \sin \theta = E \left(\frac{\text{natural frequency}}{\text{applied frequency}}\right)\left(\frac{\text{cut-off current}}{\text{normal crest current}}\right)$$
$$= \sqrt{\frac{L}{C}}\, I_{c\cdot o\cdot} \tag{10}$$

This equation shows that:

(a). The higher the natural frequency of the circuit the greater the amplitude. Since the natural frequency is very closely

$$w = \sqrt{A^2 - a^2} \cong \frac{1}{\sqrt{LC}} \tag{11}$$

it is clear that the amplitude of oscillation is inversely proportional to the square root of the capacitance. Hence, the addition of capacitance will decrease the amplitude.

(b). The higher the current at which rupture occurs the greater the voltage. In fact, the recovery voltage is directly proportional to the cut-off current. It is not yet clear if there is a maximum cut-off current at which a given switch can rupture the circuit. If so, then the higher the normal crest current in a circuit. the smaller the recovery voltage, since it is the *ratio* of *cut-off* to *normal* current which is important in equation 11; and therefore if there is an upper limit to the cut-off current (for a given switch), normal current is important.

As an example let:

$$E = \sqrt{2} \times 2{,}000 = 2{,}828$$
$$L = 0.25 \text{ henrys}$$
$$C = 0.003 \text{ microfarad}$$
$$\omega = 2\pi f = 377$$
$$a = 0.003 \times 10^6$$
$$b = 0$$
$$\theta = 10° \ (\sin \theta = 0.173)$$
$$w = \frac{1}{\sqrt{LC}} = 36{,}500$$

By 9, if t is in microseconds

$$e = 2828 \left[\cos (0.000377t - 10°) - \left(0.985 + \frac{3000}{377} \times 0.173\right) \times \epsilon^{-0.003t} \cos 0.0365t - \frac{36500}{377} \times 0.173\, \epsilon^{-0.003t} \sin 0.0365t\right]$$
$$= 2828 \cos (0.000377t - 10°) - 6690\, \epsilon^{-0.003t} \cos 0.0365t - 47400\, \epsilon^{-0.003t} \sin 0.0365t$$

This has a maximum of 43,000 volts, or 15 times normal. The value of a used in this problem corresponds to a leakage resistance of about 55,000 ohms.

Shunt Resistor

The circuit can be rendered nonoscillatory by the addition of a shunt resistor such that

$$(a^2 \geq A^2) \text{ or } \frac{1}{4}\left(\frac{G}{C} + \frac{R}{L}\right)^2 \geq \left(\frac{RG + 1}{LC}\right) \tag{12}$$

or approximately

$$G \geq 2\sqrt{\frac{C}{L}} \tag{13}$$

Under this condition the high frequency oscillation is adequately suppressed. Taking the example in the previous case, and assuming a shunt resistor of 6,000 ohms, we have by 4

Table II

Event	Instant	Initial Conditions: Current	Initial Conditions: Voltage	Dielectric Strength	Switch Voltage	Switch Current	Reactor Voltage	Reactor Current
Begin to rupture $i_s(t_1, 0) = 0$	0	$I_0 = -I \sin\theta$	$E_0 = E\cos\theta$		$f(t)$	$i_s(t, 0)$	$e(t, 0)$	$i(t, 0)$
First rupture $E_s(t_2) = \bar{e}_s(t_2, t_1)$	t_1	$I_1 = i(t_1, 0)$	$E_1 = e(t_1, 0)$	$E_s(t)$	$\bar{e}_s(t, t_1)$	0	$\bar{e}(t, t_1)$	$\bar{i}(t, t_1)$
First restrike $i_s(t_3, t_2) = 0$	t_2	$I_2 = \bar{i}(t_2, t_1)$	$E_2 = \bar{e}(t_2, t_1)$		$f(t)$	$i_s(t, t_2)$	$e(t, t_2)$	$i(t, t_2)$
Second rupture	t_3	$I_3 = i(t_3, t_2)$	$E_3 = e(t_3, t_2)$	$E_s(t)$	$\bar{e}_s(t, t_3)$	0	$\bar{e}(t, t_3)$	$\bar{i}(t, t_3)$

Table III

Event	Instant	Initial Conditions: Current	Initial Conditions: Voltage	Dielectric Strength	Switch Voltage	Reactor Voltage	Reactor Current
First rupture $E_s(t_1) = \bar{e}_s(t_1, 0)$	0	$I_0 = -I \sin\theta$	$E_0 = E\cos\theta$	$E_s(t)$	$\bar{e}_s(t, 0)$	$\bar{e}(t, 0)$	$\bar{i}(t, 0)$
First restrike $E_s(t_2) = \bar{e}_s(t_2, t_1)$	t_1	$I_1 = \bar{i}(t_1, 0)$	$E_1 = E\cos(\omega t_1 - \theta)$	$E_s(t)$	$\bar{e}_s(t, t_1)$	$\bar{e}(t, t_1)$	$\bar{i}(t, t_1)$
Second restrike $E_s(t_3) = e_s(t_3, t_2)$	t_2	$I_2 = \bar{i}(t_2, t_1)$	$E_2 = E\cos(\omega t_2 - \theta)$	$E_s(t)$	$\bar{e}_s(t, t_2)$	$\bar{e}(t, t_2)$	$\bar{i}(t, t_2)$
Third restrike	t_3	$I_3 = \bar{i}(t_3, t_2)$	$E_3 = E\cos(\omega t_3 - \theta)$	$E_s(t)$	$\bar{e}_s(t, t_3)$	$\bar{e}(t, t_3)$	$\bar{i}(t, t_3$

$$a = \frac{1}{2}\left(\frac{167}{0.003}\right) = 28{,}000$$

$$w = \sqrt{A^2 - a^2} \cong \sqrt{\frac{1}{LC} - a^2} = \sqrt{\frac{10^6}{0.25 \times 0.003} - 28{,}000^2} = 23{,}450$$

Hence by 5 there is approximately

$$e = 2828\left(\frac{36500}{23450}\right)^2\left\{\frac{1}{2.42}\cos(0.000377t - 10°) + 11.28\,\epsilon^{-0.028t}\sin(0.02345t - 58.6°)\right\}$$

$$= 2828\cos(0.000377t - 10°) + 77500\,\epsilon^{-0.028t}\sin(0.02345t - 58.6°)$$

The high-frequency oscillation has a maximum at (t = 73) of 6,350 volts, and the total voltage does not exceed 3 times normal, as compared with 15 times normal for the case without shunt resistor.

Had the shunt resistor been "critical," as called for by 13—about 4,500 ohms—the transient term would have been of no concern. It is suggested that 13 be adopted as the proper criterion for a shunt resistor.

Thyrite Shunt

When a Thyrite shunt resistor is employed to suppress the magnitude and rate-of-recovery of the transient, it is necessary to resort to step-by-step calculations. Assuming, as before, that the switch opens at an angle θ from a normal current zero, and neglecting the arc drop, the initial conditions immediately following rupture of the switch current are:

$$i_L = -I\sin\theta \tag{14}$$

$$e_c = E\cos\theta \tag{15}$$

$$i_s = 0 = i_L + i_R + i_C \tag{16}$$

Substituting increments for differentials there is

$$\Delta e_c = \frac{i_C}{C}\,\Delta t = -\left(\frac{i_L + i_R}{C}\right)\Delta t \tag{17}$$

$$e_c = E\cos\theta + \Sigma\Delta\theta_c \tag{18}$$

$$\Delta i_L = \frac{e_{av}}{L}\,\Delta t \tag{19}$$

$$i_L = -I\sin\theta + \Sigma\Delta i_L \tag{20}$$

$$i_R = \phi(e_c) = \text{Thyrite current as function of the voltage} \tag{21}$$

Herefrom the step-by-step calculation can be performed in the following sequence:

Δt	t	Δi_L	i_L	i_R	Δe_C	e_C
	0		$-I\sin\theta$	$\phi(E\cos\theta)$		$E\cos\theta$
(1)		(3)			(5)	
	(2)		(4)	(7)		(6)

Appendix II

Recurrent Restriking

Current interruption at other than a normal current zero results in the initiation of a greatly magnified voltage transient. If this voltage transient is able to overtake the increasing dielectric strength of the opening switch contacts, the arc will restrike and thus postpone the final rupture of the circuit. A number of restrikes may occur in succession before the switch gap is able to sustain the recovery voltage. In effect, a series of restrikes is equivalent to circuit interruption at a lower current than prevailed at the first attempt; so that the transient recovery voltage is substantially reduced. Moreover, since the switch contacts have been continually parting during the restriking period, the dielectric strength of the opening switch has ample time to become established and effect the final rupture.

An additional interesting fact associated with restriking of the switch is the possibility of obtaining *higher* recovery voltages by increasing the circuit capacitance, which is quite contrary to the case when no restriking occurs. The reason for this is that the addition of capacitance not only reduces the crest of the transient recovery voltage (inversely as the square root of the capacitance), but also reduces the natural frequency in the same proportion. It is thus possible for the switch to open with fewer restrikes, or even to escape restriking entirely, if the natural frequency is reduced, and on this account a higher recovery voltage results. Of course, if capacitance is added beyond that necessary to just avoid restriking, there is a decrease of recovery voltage.

There are 2 kinds of "events" associated with recurrent restriking of the switch arc: (a) the characteristic transient during arcing and, (b) the characteristic transient when the switch is clear. Each of these transients depends upon the currents and voltages existing at the initiation of the event; and these initial values are determined from the corresponding end conditions of the preceding event.

The analysis consists, then, in deriving the appropriate equations for each kind of transient, and the formulation of a procedure for determining the integration constants in proper sequence. In the interests of simplicity a circuit consisting of L and C in parallel will be considered.

Arcing Conditions

During arcing of the switch the voltage applied to the circuit is

$$e = E\cos(\omega t - \theta) - f(t) \qquad (1)$$

in which $E\cos(\omega t - \theta)$ is the applied normal frequency voltage and $f(t)$ is the arc drop expressed as a function of time t. More generally, the arc drop depends upon the current, kind of contacts, and other factors, but will be here regarded merely as a function of the switch opening, hence of time. Park and Skeats[1] have given an example (their figure 12) in which the arc drop at the instant of clearing was taken into account in calculating the recovery transient. Recently C. Concordia, in an unpublished report, has calculated the recovery voltage assuming the arc drop to be a linear function of time Kt, and under this assumption has found for slow rates of increase of the arc voltage that the recovery voltage tends to become independent of the circuit constants, while for fast rates it tends to become independent of the switch characteristics.

Adhering, for the sake of generality, to $f(t)$ as the arc drop, the current through the inductance is

$$i = \frac{1}{L}\int [E\cos(\omega t - \theta) - f(t)]\,dt = A + \frac{E}{\omega L}\sin(\omega t - \theta) - F(t) \qquad (2)$$

in which A is an integration constant and

$$F(t) = \frac{1}{L}\int f(t)\cdot dt \qquad (3)$$

If $i = I_j$ at $t = t_j$ then

$$i = I_j + \frac{E}{\omega L}[\sin(\omega t - \theta) - \sin(\omega t_j - \theta)] - [F(t) - F(t_j)] \qquad (4)$$

The capacitance current is

$$i_c = C\frac{de}{dt} = -\omega CE\sin(\omega t - \theta) - C\cdot f'(t) \qquad (5)$$

and the total switch current is the sum of (4) and (5) or

$$i_s = I_j + \frac{E}{\omega L}[(1 - \omega^2 LC)\sin(\omega t - \theta) - \sin(\omega t_j - \theta)] - [F(t) - F(t_j)] - C\cdot f'(t) \qquad (6)$$

If $f(t)$ is known, or assumed, the transcendental equation 6 determines the instant $t_j + 1$ at which the switch current is passed through zero; and then (1) and (4) give the capacitor voltage and inductance current at this instant.

Nonarcing Condition

When there is no arc across the switch the differential equation is

$$\frac{d^2i}{dt^2} + \frac{i}{LC} = 0 \qquad (7)$$

for which the solution is

$$i = A\cos wt + B\sin wt \qquad (8)$$

and

$$e = L\frac{di}{dt} = -wLA\sin wt + wLB\cos wt \qquad (9)$$

in which

$$w = \frac{1}{\sqrt{LC}}$$

If $i = I_k$ and $e = E_k$ at $t = t_k$ these give

$$\bar{i} = I_k\cos w(t - t_k) + \frac{E_k}{wL}\sin w(t - t_k) \qquad (10)$$

$$\bar{e} = -wLI_k\sin w(t - t_k) + E_k\cos w(t - t_k) \qquad (11)$$

in which bars have been placed over the quantities to distinguish them from the corresponding quantities under the arcing condition. The voltage across the switch is

$$\bar{e}_s = E\cos(\omega t - \theta) - \bar{e} \qquad (12)$$

and the dielectric strength of the open switch will be taken as a function of time $E_s(t)$. Here again, the dielectric recovery strength is probably a function of the previous arc current and other factors, but will be considered as a simple function of the switch opening, that is of the time. It is clear from the test results that $E_s(t)$ is not linear. In many cases it first decreases and then increases, and is sometimes very erratic.

Restriking

Suppose the switch makes its first attempt to open the circuit at time $t_j = t_0 = 0$ at which instant

$$e(0) = E_0 = E\cos\theta + f(0) \qquad (13)$$

$$i(0) = I_0 = \frac{-E}{\omega L}\sin\theta \qquad (14)$$

Hence by (6) the switch current is

$$i_s(t, 0) = \frac{E}{\omega L}(1 - \omega^2 LC)\sin(\omega t - \theta) - F(t) + F(0) - C\cdot f'(t) \qquad (15)$$

Equating (15) to zero and solving for $t = t_k = t_1$ gives the instant at which the current extinguishes, at which instant

$$\text{by (1)}: e(t_1, 0) = E\cos(\omega t_1 - \theta) + f(t_1) = E_1 \qquad (15)$$

$$\text{by (4)}: i(t_1, 0) = \frac{E}{\omega L}\sin(\omega t_1 - \theta) - F(t_1) + F(0) = I_1 \qquad (17)$$

Substituting (16) and (17) into (10) and (11) there is

$$\bar{i}(t, t_1) = I_1\cos w(t - t_1) + \frac{E_1}{wL}\sin w(t - t_1) \qquad (18)$$

$$\bar{e}(t, t_1) = -wLI_1\sin w(t - t_1) + E_1\cos w(t - t_1) \qquad (19)$$

$$\bar{e}_s(t, t_1) = E\cos(\omega t - \theta) + wLI_1\sin w(t - t_1) - E_1\cos w(t - t_1) \qquad (20)$$

This condition persists until a time $t = t_j = t_2$ such that

$$\bar{e}_s(t_2, t_1) = E_s(t_2) \qquad (21)$$

when the arc restrikes. The end conditions at $t = t_2$ are then given by (18) and (19) as

$$\bar{i}(t_2, t_1) = I_2 \qquad (22)$$

$$\bar{e}(t_2, t_1) = E_2 \qquad (23)$$

and these substituted in (4) and (6) give the initial conditions for the next arcing event. The sequence is then repeated according to table II.

If the current rupture is assumed to be abrupt, the procedure can be simplified to the form of table III.

It will be noticed in the above tabulation that the initial voltage E_k for each event (following restrike) is merely the applied normal frequency voltage at that instant; for the restriking of the arc places the capacitance directly across the applied voltage and we are neglecting the arc drop.

Of great interest is the possibility of discontinuing the high-voltage transient following a restrike near the peak of the voltage transient.

The dangerous component of the voltage transient is the term containing I_k in equation 11, and therefore if $I_k = 0$ this term vanishes. But

$$I_k = -I_{k-1} \cos w (t_k - t_{k-1}) + \frac{E_{k-1}}{wL} \sin w (t_k - t_{k-1}) \qquad (24)$$

and thus the condition $I_k = 0$ is satisfied by

$$\tan w (t_k - t_{k-1}) = \frac{wLI_{k-1}}{E_{k-1}} = \frac{w}{\omega} \frac{\omega LI_{k-1}}{E_{k-1}} \qquad (25)$$

Now w/ω is usually large (say of the order 100 to 1) and therefore even for small values of I_{k-1} equation 25 shows that the $\tan w(t_k - T_{k-1})$ is large, so that the condition corresponds to a restrike near the peak of the voltage oscillation. A number of oscillograms illustrating this condition have been given in the text. Of course, tests with d-c are particularly favorable to this condition.

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The Enlarging Concept of Engineering

By VLADIMIR KARAPETOFF, Fellow AIEE

IN proportion as the concept of "laws of nature" grows larger to include individual human behavior and group action, the engineer is called upon to apply his time-tested methods to broader problems of state and country. The usual definition of engineering, as the science and art of applying laws of nature to human needs, still holds; only the laws of nature cannot be limited any longer to those of levers and expanding steam. Sales engineering and works management have been the two windows through which the mechanistically minded engineer has been made to see broader aspects of his profession, involving fickle human will, prejudices, and emotional response. It is true that these propensities cannot yet be predicted with the same accuracy as the strength of a beam or the behavior of an electric generator, but the engineer has always included a lot of intuitive art (horse sense) as a part of his professional make-up anyway. As the laws of human behavior become better known we may expect an ever increasing influence of properly trained engineers upon our political, economic, and social life.

A person who can play fragments of half a dozen pieces on the piano in a crude fashion is not a musician worthy of that name. The new engineer whom I am picturing is not a man who barely has had short courses in elementary psychology and economics, in addition to his big courses in machine design and laboratories. My plea is primarily for a longer college course, following the example of the professions of law and medicine. Our nation must be awakened to the great possibilities of scientific planning and systematic gradual realization of an all-embracing economic and social program, a plan that would carry us as little scathed as possible beyond the present unrest and uncertainties. The men and women who know what is needed and what is possible to accomplish to save this country from a chaos do not yet call themselves engineers. They may be historians, sociologists, economists, psychologists, or what not. But once they are called upon to lay down definite plans and to execute them, they become engineers, for they will have to employ practically the same rigid methods of design and management as those used in building a mammoth bridge or running a huge automobile plant. Thus, these human engineers of the new kind should have considerable general engineering ability and training, and at the same time be experts in one of the lines of "social engineering." An analogy with a medical specialist readily suggests itself.

I am unalterably opposed to anything superficial in engineering training in colleges, for with the present spread of popular information superficial knowledge is readily picked up from the daily and weekly press and by simply keeping one's eyes open. The ranks of the new engineers should not be filled from among so-called practical youths who cannot master mathematics or mechanics. The social engineer has to be even more analytical than his older mechanistically inclined colleague, for he is to apply himself to much more difficult problems and to problems whose solutions cannot be looked up in a handbook like the size of an I-beam. The only choice left is to lengthen the course of training to five or even six years. No student should be allowed to specialize for at least three years; during these years he should be imbued with the general point of view of an engineer, using as illustrations some simple problems taken from two or three usual domains of engineering activity. This means a training both in the fundamental sciences and in applied situations. From there on, the attention devoted to one or two chosen specialties should be gradually increased, and the time devoted to the other engineering subjects tapered down.

Social engineers alone can convert our present society into a properly subdivided and inwardly correlated politico-economic unit wherein each of us could move in his proper sphere without dominating others or being dominated by them. My appeal is for such social engineers.

From an address delivered by the author before the trustees, the faculty, and invited guests of the Polytechnic Institute of Brooklyn, at the University Club, New York, N. Y., June 16, 1937, on the occasion of granting him an honorary degree of doctor of science. Doctor Karapetoff is professor of electrical engineering at Cornell University, Ithaca, N. Y.

Network-Analyzer Solution of Multiple Unbalances

By EDWARD W. KIMBARK
MEMBER AIEE

SOME EXAMPLES of multiple unbalances on a 3-phase network are:

1. Two or more unsymmetrical short circuits at different points of a network. Faults involving more than one circuit are not unusual on multicircuit lines, and simultaneous faults sometimes occur even at geographically separated points, especially on systems grounded through high impedance. System stability or operation of relays during such faults may require investigation.
2. A short circuit partially cleared by the blowing of a fuse.
3. A short circuit on a line having series capacitors, the capacitors in the faulted conductor being short circuited by protective devices.
4. Two or more single-phase or unbalanced loads.

The solution for current, voltage, and power at specified points of such a network containing any one of the multiple unbalances listed above is greatly facilitated by the use of a network analyzer (a-c calculating board). The a-c board is a much more powerful tool than the d-c board for solving multiple unbalances, and its use for this purpose saves even more time and labor than it does in solving single unbalances. The technique of its use is of interest at this time in view of the increasing use and importance of network analyzers.

A number of different methods are available for the network-analyzer solution of multiple unbalances. The method to be preferred in any particular case depends on the nature of the problem to be solved and on the equipment available.

The methods may be broadly classified into symmetrical component methods and 3-phase methods. Several symmetrical component methods, which have been published,[1,2,3] will be summarized and compared with each other and with the 3-phase methods. The latter will be described in detail.

I. Symmetrical-Component Methods

In the symmetrical component methods the 3-phase network is represented on the calculating board by its sequence networks, set up either together or in succession.

A. Equivalent-Circuit Method

This method was devised by Miss Clarke[1] for the case of 2 simultaneous faults, and is suitable for all types of double unbalance. The 2 faults (or double unbalance) are represented by a 3-terminal equivalent circuit connected to the positive-sequence network at the 2 points of fault and the neutral point. In some cases the equivalent circuit must contain an adjustable source of voltage. The impedances of the equivalent circuit depend on the impedances of the zero-sequence and negative-sequence networks measured from the points of fault and on the types of faults or of unbalance.

The determination of the impedances of the equivalent circuit requires algebraic work which, however, has been done and tabulated for combinations of 2 short circuits. The equivalent circuit must be modified if any change occurs in the zero- or negative-sequence networks, as, for example, by the opening of a line; but it is not affected by swinging of the generators except in so far as this may require readjustment of the electromotive force of the equivalent circuit. The equivalent-circuit method has the advantage of requiring only one sequence network to be set up at a time, thus permitting a large power system to be represented with the minimum number of phase shifters and impedance units. It is particularly good for problems, such as stability studies, in which only the positive-sequence quantities are of interest. If zero- or negative-sequence quantities are desired the respective networks must be solved separately. The method is limited to two simultaneous faults (or a double unbalance).

B. Shunt Method

This method, which was suggested by Professor W. V. Lyon,[2] is similar to the preceding one except that each fault is represented by a single impedance connected in shunt with the positive-sequence network at the point of fault. The impedance of each shunt depends not only on the impedances of the zero- and negative-sequence networks and on the types of all the faults, but also on the impedances of the positive-sequence networks and on the ratio of the open-circuit positive-sequence voltages at the points of fault. As a result, the impedances of the fault shunts are affected by swinging of generators if the ratio of open-circuit fault voltages is affected thereby, as it generally is. Professor Lyon has worked out expressions for the values of the shunts representing 2 faults. The method can be extended to any number of simultaneous faults by suitable algebraic determination of the values of the shunts.

C. Connection Method

This method requires all 3 sequence networks to be set up at the same time, and is therefore limited to a smaller system than are the 2 preceding methods. Any number of simultaneous short circuits or open circuits or both may be represented by suitable interconnections of the sequence networks as has been customary for representing single short circuits, except that in some cases the connections must be made through insulating transformers or through phase converters. The phase converter is any device

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1. For all numbered references, see list at end of paper.

which either automatically or by manual adjustment satisfies the conditions that its terminal voltages be exclusively of positive sequence and that its line currents be exclusively of negative sequence. A device of this kind, employing an induction machine as suggested in reference 3, has been successfully used with the Massachusetts Institute of Technology network analyzer. The connections for representing 2 simultaneous line-to-ground faults, one on phase a, the other on phase b, are shown in figure 1. The interconnections are not affected by changes

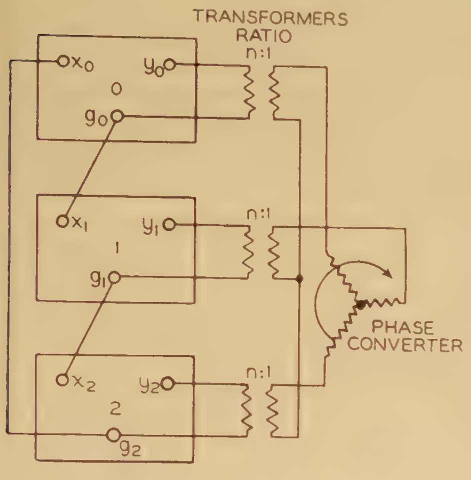


Figure 1. Connections between the sequence networks for representing simultaneous AG-BG short circuits

in the system, such as opening or closing of lines or swinging of generators, except in so far as these changes may necessitate readjustment of the phase converter, if one is used. This method dispenses with impedance measurements and the calculation required in the previous 2 methods for determining the fault shunts or the equivalent circuit, and is therefore more convenient if the size of system permits its use, particularly if zero- and negative-sequence quantitites are to be read. In case of simultaneous faults not all having the same phase of symmetry, the necessity for using a phase converter, which is not now standard equipment of any network analyzer, may be regarded as a disadvantage of the method.

II. Three-Phase Methods

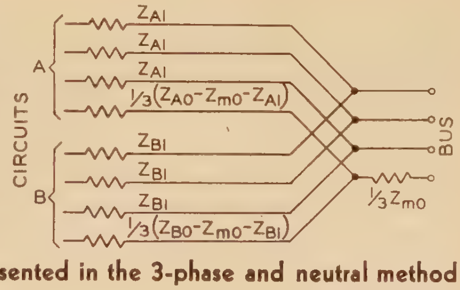
Although it has been customary to use the method of symmetrical components for fault studies on 3-phase networks, it is possible and often preferable to use either the phase quantities directly or substituted variables other than symmetrical components. This is particularly true when the values of phase currents and voltages are wanted, as in studies of relay operation. Two methods utilizing 3-phase set-ups will be described, both of which require the assumption that the positive- and negative-sequence networks are identical except as to generated electromotive forces, but neither of which requires the zero-sequence network to be like the positive- or negative-sequence networks. A method which did so restrict the zero-sequence network would not be of much value for representing a 3-phase power system, because of the great difference between the zero- and positive-sequence impedance of transmission lines, and because of the effects of various transformer connections.

The positive- and negative-sequence networks are, of course, identical except for the effects of polyphase rotating machinery, generators in particular. It is pertinent, therefore, to inquire as to the difference between the positive- and negative-sequence impedances of generators. Either the transient reactance (x_d') or the subtransient reactance (x_d'') is use for the positive-sequence impedance of synchronous machines in fault studies, depending on how soon after the occurrence of the fault is the instant for which the fault currents are wanted. The following values of the ratios of negative-sequence reactance x_2 to transient and subtransient positive-sequence reactances are averaged from test results published by Wright.[4]

Type of Machine	x_2/x_d'	x_2/x_d''
Round-rotor turbogenerators	0.64	1.00
Salient-pole machines with dampers	0.64	0.96
Salient-pole machines without dampers	1.50	1.50

These ratios range from about 2/3 to 3/2; hence it would seem that in many cases the assumption that $Z_1 = Z_2$ would not be too bad, especially when it is considered that there are nearly always transformers and lines between the generators and the faults.

Figure 2. Representation of 2 transmission lines with zero-sequence mutual impedance, connected to the same bus at the right-hand end, as represented in the 3-phase and neutral method



In cases in which the difference between positive- and negative-sequence impedance may be of importance, it may be taken into account by a method described later in this paper.

A. Three-Phase and Neutral Method

This method was independently devised and used on the Westinghouse and Massachusetts Institute of Technology network analyzers.

1. *Representation of System.* The power system is represented as a 3-phase 4-wire circuit. The 3 line conductors of each branch have impedances equal to the positive- or negative-sequence impedance Z_1 of the branch, while the impedance Z_n of the neutral conductor is given by $Z_n = \frac{1}{3}(Z_0 - Z_1)$. Positive- and negative-sequence components of current are confined to the line wires and therefore produce the correct IZ drops in the line-to-neutral voltage. If zero-sequence components of current are present, they have the same value I_0 in each line conductor. Assuming that the sum of these components, $3I_0$, returns in the neutral conductor, the drop in line-to-

neutral voltage produced in the branch by the zero-sequence current is the same for each phase and has the magnitude

$$I_0Z_1 + 3I_0 \times \frac{1}{3}(Z_0 - Z_1) = I_0Z_0$$

which is correct. Zero-sequence mutual impedance Z_{m0} between 2 parallel transmission lines connected to the same bus at one end may be represented as shown in figure 2. Here the drop in line-to-neutral voltage of circuit A is:

$$I_{A0}Z_{A1} + 3I_{A0} \times \frac{1}{3}(Z_{A0} - Z_{m0} - Z_{A1}) + (3I_{A0} + 3I_{B0}) \times \frac{1}{3}Z_{m0} = I_{A0}Z_{A0} + I_{B0}Z_{m0}$$

Shunt capacitance of lines, if appreciable, may be represented as in figure 3, in which C_1 is the positive-sequence capacitance and C_n has the value $3\ C_0C_1/(C_1 - C_0)$, where C_0 is the zero-sequence capacitance.

The potential drops due to zero-sequence current are not correct unless the zero-sequence currents actually return in the neutral wire, as assumed. That is, in every branch of the 3-phase network, we must have

$$I_a + I_b + I_c + I_n = 0$$

or

$$I_n = -(I_a + I_b + I_c) = -3I_0$$

This requirement is automatically satisfied in all radial branches of the 3-phase network. If the network has one or more closed loops, the currents in general will not satisfy this requirement automatically but they may be forced to do so by inserting "forcing transformers" in series with one or more branches. Figure 4 shows several alternative arrangements of forcing transformers; scheme (*d*) is perhaps the most practical. The number of banks of forcing transformers is, in general, equal to the number of independent loops in the 3-phase network, but in some networks the impedances are so related that correct current distribution is obtained even though fewer or no

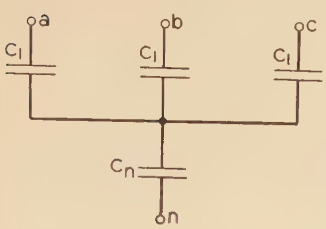


Figure 3. Representation of shunt capacitance in the 3-phase and neutral method

banks are used. If there should be doubt in a specific case as to the proper number and location of forcing transformers, the best procedure would be to set up the network without forcing transformers and to measure the line and neutral currents in rectangular form in several branches of the network. The sum of the 3 line currents should then be compared with the neutral current. If the agreement should not be satisfactory, forcing transformers should be inserted, and the check readings should again be taken.

Generator voltages are represented by balanced 3-phase electromotive forces. Three phase-shifters connected in Y may be used to represent either grounded or ungrounded generators; or 2 phase-shifters connected in V, to represent ungrounded generators. Phase-shifters with 3-phase output are not suitable because the internal impedance drops due to unbalanced loads produce unbalanced terminal voltages.

The terminal voltages of the phase shifters may be purposely unbalanced (as suggested by Professor L. F. Woodruff) to represent the effect of the difference between the positive- and negative-sequence impedances of a generator. To do so, the generator phase currents are measured with balanced phase-shifter voltage, and the negative-sequence current I_2 and the voltage $V_2' = I_2(Z_1 - Z_2)$ are computed from them. The phase-shifter terminal voltages are then changed by the addition of voltages V_2', aV_2', and a^2V_2' to phases a, b, and c, respectively.

Transformer banks in the power system may be rep-

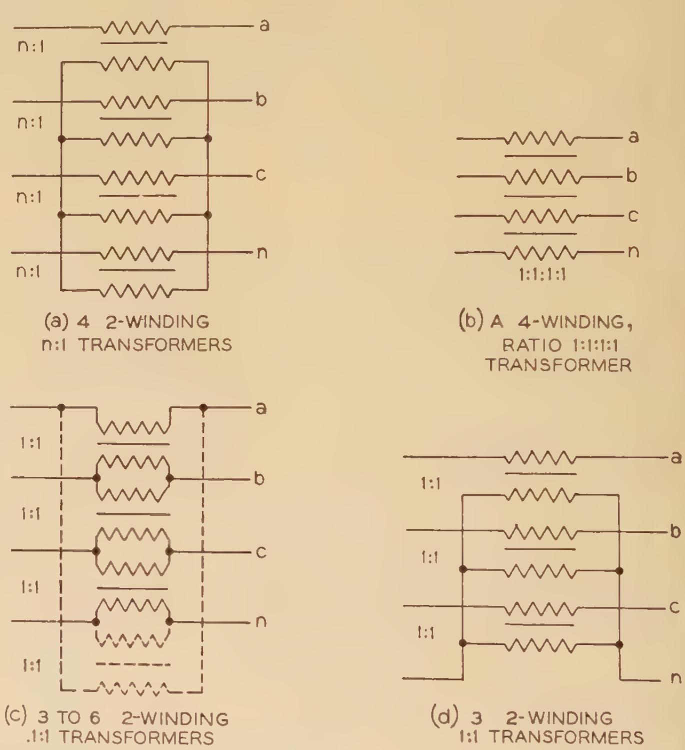


Figure 4. Connections of forcing transformers for use in the 3-phase and neutral method

resented on the network analyzer by actual transformer banks or, in some cases, by simple series impedances, as shown in figure 5. The representation of Δ-Y banks by series impedances does not directly give the correct currents and voltages on the side of the transformer away from the fault (this is also true of symmetrical-component methods), and cannot be used in case of simultaneous faults on opposite sides of such banks.

2. *Representation of Unbalance.* Faults are applied by making the actual fault connection, connections to ground being made to the corresponding point of the neutral network. Any number of faults, on any phases, may be ap-

plied simultaneously without causing complications. Unbalanced loads or unbalanced series impedances are represented just as simply.

3. *Measurements.* The following quantities can be measured directly: line currents, residual current (in neutral), line-to-line voltages, line-to-ground voltages (measured line to neutral). Residual voltage can be read by the use of 3 potential transformers having their primary windings connected line-to-neutral and their secondary windings in series, or can be computed as the sum of the line-to-ground voltages. Positive-sequence and negative-sequence quantities are not so conveniently obtained, but they can be computed or measured by the same methods which can be used to obtain phase quantities from a symmetrical-component representation.

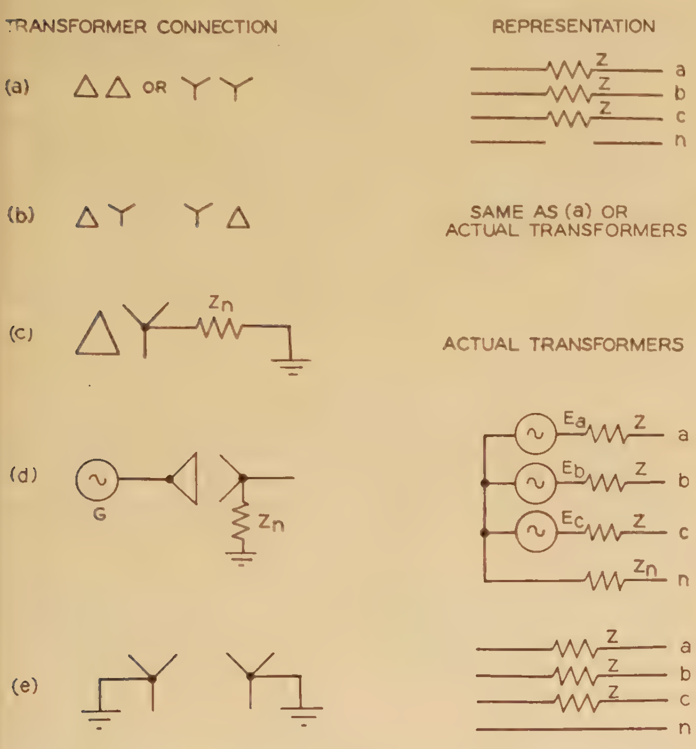


Figure 5. Representation of transformer banks in the 3-phase and neutral method

4. *Advantages and Disadvantages.* This method requires 4 impedance units per branch of the one-line system diagram, and thus is limited to smaller systems than are the equivalent-circuit and shunt methods. It requires 3 phase-shifters per generator, thus limiting the number of generators which can be represented and giving more trouble in adjusting the generator phase angles or outputs. Forcing transformers are required in many cases to give correct current distribution in the network. It is necessary to assume that the negative-sequence impedance of each branch is equal to the positive-sequence impedance.

On the other hand, the representation of simultaneous faults and unbalances of any kind is extremely simple. Phase and residual currents, line-to-line and line-to-neutral voltages can be read directly.

The best field of application is to networks of small or medium size and principally at one voltage, with only one or two equivalent generators, and to problems (such as relay studies) in which phase quantities are required.

B. Three-Phase and Zero-Sequence Method

This method differs from the preceding one in that zero-sequence current and voltage are excluded from the 3-phase network and confined to a separate network. The fault connections and the methods of measurement are not quite as simple as in the method just described, but the correct current distribution is obtained without recourse to forcing transformers.

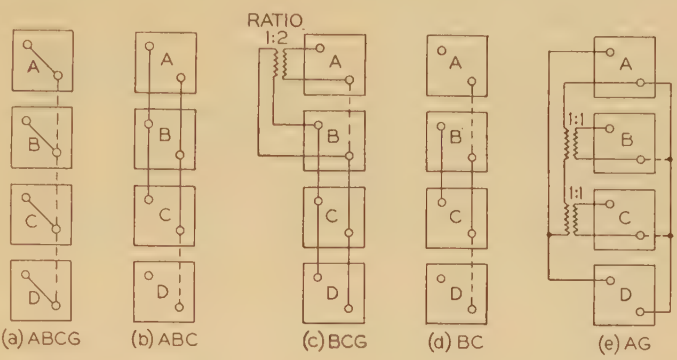


Figure 6. Connections between the substitute networks for representing various types of short circuits, 3-phase and zero-sequence method

The theory of the method is explained in the appendix. Four substitute networks, designated as A, B, C, and D, are set up on the network analyzer. Networks A, B, and C have in each branch an impedance equal to the positive- (or negative-) sequence impedance, while network D (which might be termed the zero-sequence network) has an impedance equal to one-third the zero-sequence impedance of the corresponding branch of the power system. Expressed symbolically, $Z_A = Z_B = Z_C = Z_1 = Z_2$, and $Z_D = \frac{1}{3} Z_0$. Networks A, B, C contain 3-phase electromotive forces, but network D has none. The currents and voltages in networks A, B, and C are the phase quantities minus their zero-sequence components. The current and voltage in network D are related to the zero-sequence quantities as follows:

$$I_D = -3I_0 \quad \text{and} \quad V_D = -V_0$$

The connections between the substitute networks for representing various kinds of short circuits are derived in the appendix and are shown in figure 6. The dotted lines indicate connections which are put in merely for convenience in measuring line-to-line voltages. Note that the connections for faults not involving ground are, as in the preceding method, the actual fault connections; whereas for the BCG and AG faults direct connections are made in accord with the actual fault connections (regarding network D as the ground), and are supplemented

by connections through transformers to the unfaulted phases. Faults on phases other than those for which connections are given are represented by similar connections with an appropriate interchange of networks A, B, and C. Simultaneous faults are represented by making the connections for each fault just as for a single fault.

After having made the appropriate fault connections, the following quantities may be measured directly as indicated: line-to-line voltages, between corresponding points of networks A, B, C; line-to-ground voltages, between corresponding points of network A, B, or C and network D; residual current, in network D; zero-sequence voltage in network D. Furthermore, the phase currents may be read by the use of a 3-to-1 current transformer with its primary winding plugged into network D and its secondary winding connected to the measuring device in parallel with a cord plugged into the corresponding branch of the phase network. (See equations $A1$ to $A3$ of appendix.)

C. Triple-Connection Method

This method, using a 3-phase and symmetrical-component representation, could be classified under either heading.

The procedure is as follows:

1. Set up each sequence network in triplicate, that is, set up 3 zero-sequence networks, 3 positive-sequence networks, and 3 negative-sequence networks. The 3 positive-sequence networks should differ from one another only in that the electromotive forces

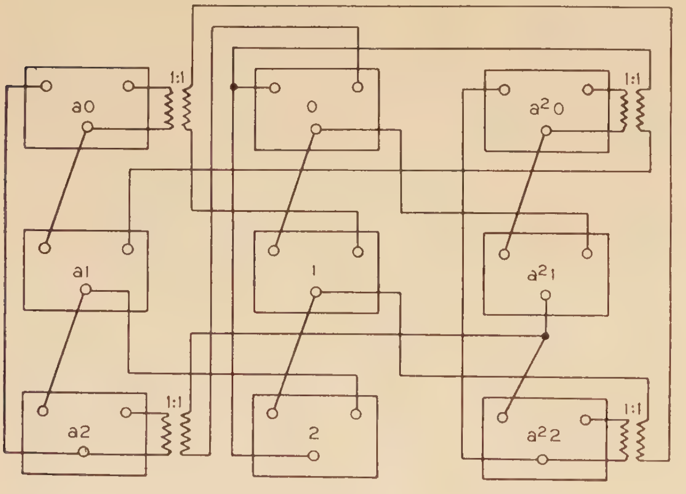


Figure 7. Connections between the triple sequence networks for representing simultaneous AG-BG short circuits, triple-connection method

in any one of them are 120 degrees ahead of the corresponding electromotive forces in another and 120 degrees behind those of the third. Phase-shifters having a 3-phase output are suitable sources of the electromotive forces.

2. At each point of fault make appropriate connections between the sequence networks to represent the given type of fault. These connections can be best understood by considering a particular case, such as simultaneous AG-BG faults, figure 7. Let the current and voltage at the left-hand terminal of network 0 be I_{x0} and V_{x0}, respectively, and at the right-hand terminal, I_{y0} and V_{y0}. Then assume for the time being that the corresponding quantities of network $a0$ are aI_{x0}, aV_{x0}, aI_{y0}, and aV_{y0}, where $a = \angle 120°$, and that the corresponding quantities of network a^20 are a^2I_{x0}, a^2V_{x0}, a^2I_{y0}, and a^2V_{y0}, respectively; and similarly for the positive- and negative-sequence networks; that is, assume that all currents and voltages at the terminals of and within the networks of the left-hand column are equal in magnitude to, but 120 degrees ahead of, the corresponding currents and voltages of the middle column of networks, and that likewise the right-hand column is 120 degrees behind the middle column. These assumptions are justified by the fact the 3 columns are identical, except for the 120-degree phase displacement of the positive-sequence electromotive forces, and by the fact that the connections to be established between the networks have a cyclical symmetry. It will be recalled that the equations for the AG fault at x are:

$$I_{x0} = I_{x1} = I_{x2} \quad \text{and} \quad V_{x0} + V_{x1} + V_{x2} = 0 \tag{1}$$

which are satisfied by a series connection of the left-hand (x) terminals of networks 0, 1, and 2. Multiplying equation 1 by a gives

$$aI_{x0} = aI_{x1} = aI_{x2} \quad \text{and} \quad aV_{x0} + aV_{x1} + aV_{x2} = 0 \tag{2}$$

which are satisfied by a series connection of the left-hand terminals of networks $a0$, $a1$, and $a2$. Similarly, multiplication of equation 1 by a^2 indicates a series connection of the left-hand terminals of networks a^20, a^21, and a^22. The equations for the BG fault at y are:

$$I_{y0} = a^2I_{y1} = aI_{y2} \text{ and } V_{y0} + a^2V_{y1} + aV_{y2} = 0 \tag{3}$$

and are satisfied by a series connection of the right-hand (y) terminals of networks 0, a^21, and $a2$. Multiplication of equation 3 by a gives

$$aI_{y0} = I_{y1} = a^2I_{y2} \quad \text{and} \quad aV_{y0} + V_{y1} + a^2V_{y2} = 0 \tag{4}$$

which are satisfied by a series connection of the right-hand terminals of networks $a0$, 1, and a^22. Likewise multiplication of equation 3 by a^2 points to a series connection of networks a^20, $a1$, and 2. In making these connections, which are shown in figure 7, a sufficient number of insulating transformers must be used (in this case at least 4).

In every case, a fault which is symmetrical with respect to phase a is represented by connections between networks in the same column, whereas a fault symmetrical with respect to phase b or phase c is represented by diagonal connections touching a different column in each row.

3. Read the sequence currents and voltages in any branches where they are wanted. The zero-sequence quantities are read in network 0, positive-sequence in network 1, and negative-sequence in network 2. It is also possible to read a^2 times the positive-sequence quantities in network a^21, a times the negative-sequence quantities in network $a2$, etc. Then the phase quantities may be readily calculated by adding the proper components:

$$I_a = I_0 + I_1 + I_2$$

$$I_b = I_0 + a^2I_1 + aI_2, \text{ etc.}$$

Or, better yet, by combining the proper components through instrument transformers, the phase quantities can be read directly. Thus, I_b can be obtained by paralleling the secondary windings of 3 current transformers, the primary windings of which are plugged into corresponding branches of networks 0, a^21, and $a2$; similarly V_b can be obtained by connecting in series the secondary windings of 3 potential transformers. A switching arrangement might be built to facilitate rapid successive reading of the several phase quantities. The best arrangement appears to be to do all the measuring in only 3 networks (say networks 0, 1, 2) and to interchange 2 of these networks with others in the same row. To be more specific, to read Ia, current jacks are plugged into networks 0, 1, and 2, and the sum, $I_a = I_0 + I_1 + I_2$, is read. Then to obtain I_b, the jacks are left in position, network 1 without its electromotive forces is interchanged with network a^21 without its electromotive forces, and network 2 is interchanged with network $a2$. Or, to avoid the switching of the positive-sequence networks

with respect to their power sources, it would be better to interchange network 0 with $a0$, and network 2 with $a^2 2$, and to read the sum $aI_0 + I_1 + a^2 I_2 = aI_b$, which by a suitable rotation of reference axes in the measuring instrument may be read as I_b.

The triple connection method, like the single connection method, is applicable to any number of simultaneous faults, and does not require that the negative-sequence impedances equal the positive-sequence impedances. Unlike the single connection method, it does not require a phase converter for representing faults not symmetrical

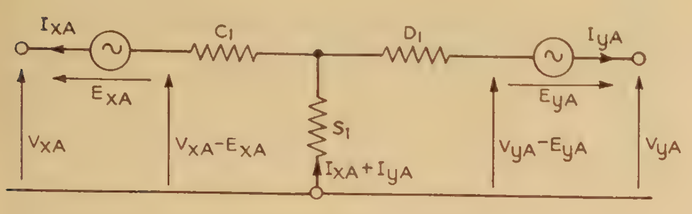


Figure 8. Equivalent T circuit to which network A (3-phase and zero-sequence method) may be reduced, retaining the 2 points of fault and the neutral point. Networks B and C can be represented similarly

with respect to phase a. Its principal disadvantage is the excessive number of impedance units required (approximately 9 units for each branch of the one-line system diagram), which makes the method impractical except for relatively small systems. An advantage is the possibility of directly reading the phase currents and voltages as well as their symmetrical components. The required number of impedance units can be decreased without losing the advantage of direct reading of phase quantities by setting up only three of the networks complete and the other six in reduced form (equivalent T or π in case of 2 simultaneous faults or a double unbalance). Readings are taken in the 3 complete networks, two of which are interchanged with reduced networks by a suitable switching device to read phase b or c quantities. The saving in number of impedance units entails the work of determining and setting up equivalent reduced circuits for each fault or system condition. If the direct reading of phase quantities be dispensed with, only one complete network need be set up at a time, the other eight being represented by equivalent circuits. However, in this case the equivalent circuit method might better be used.

Conclusion

Some new methods have been presented, and some older ones summarized and compared, for solving networks with multiple unbalances by use of a network analyzer. For stability studies, especially on large systems, with 2 simultaneous faults, the equivalent circuit method appears to be the most suitable. For the rare case of more than 2 faults the shunt method may be employed. For studies of relay operation on smaller systems and in which swinging of generators is not an important factor, the 3-phase methods are best. Of these the 3-phase-and-netural method is usually the simpler. However, on a network in which a large number of forcing transformers would be required to secure correct current distribution it appears simpler to use the 3-phase and zero-sequence method, in which transformers are used in the connections representing faults instead of as forcing transformers. In other problems, the network analyzer operator can select whatever method may appear best suited to the problem at hand.

Appendix

Theory of 3-Phase and Zero-Sequence Method and Proof of Connections for Representing Short Circuits

The method is based on a substitution of variables analogous to the one employed in the method of symmetrical components. Let I_a, I_b, I_c be the line currents and V_a, V_b, V_c the voltages to ground of the 3 conductors of the 3-phase system. Let new variables I_A, I_B, I_C, I_D and V_A, V_B, V_C, V_D, defined as follows be introduced:

$$I_a = I_A - \frac{1}{3} I_D \tag{A1}$$

$$I_b = I_B - \frac{1}{3} I_D \tag{A2}$$

$$I_c = I_C - \frac{1}{3} I_D \tag{A3}$$

in which

$$I_A + I_B + I_C = 0 \tag{A4}$$

Also let

$$V_a = V_A - V_D \tag{A5}$$

$$V_b = V_B - V_D \tag{A6}$$

$$V_c = V_C - V_D \tag{A7}$$

in which

$$V_A + V_B + V_C = 0 \tag{A8}$$

The inverse transformations are as follows:

$$I_A = \frac{1}{3}(2I_a - I_b - I_c) \tag{A9}$$

$$I_B = \frac{1}{3}(2I_b - I_c - I_a) \tag{A10}$$

$$I_C = \frac{1}{3}(2I_c - I_a - I_b) \tag{A11}$$

$$I_D = -(I_a + I_b + I_c) \tag{A12}$$

$$V_A = \frac{1}{3}(2V_a - V_b - V_c) \tag{A13}$$

$$V_B = \frac{1}{3}(2V_b - V_c - V_a) \tag{A14}$$

$$V_C = \frac{1}{3}(2V_c - V_a - V_b) \tag{A15}$$

$$V_D = -\frac{1}{3}(V_a + V_b + V_c) \tag{A16}$$

Note that four new currents, I_A, I_B, I_C, I_D, are substituted for 3 old currents I_a, I_b, I_c but that only 3 of the 4 are independent, as they are subject to the restriction expressed in equation $A4$. The

same remark applies to the substitution of voltages. The D quantities are related to the zero-sequence quantities as follows:

$$I_D = -3I_0 \quad \text{and} \quad V_D = -V_0 \tag{A17}$$

Therefore the A, B, C quantities are the phase quantities minus their zero-sequence components.

Let I_A and V_A be associated with a network A, I_B, and V_B with network B, etc. The connections between networks A, B, C, and D for representing various kinds of faults will be determined, but before doing so 2 general relations will be noted. First, as may be shown readily, the total vector power of corresponding branches of the substitute networks (A, B, C, D) is equal to the total vector power in the corresponding branch of the original 3-phase power network.

$$\overline{V}_A I_A + \overline{V}_B I_B + \overline{V}_C I_C + \overline{V}_D I_D = \overline{V}_a I_a + \overline{V}_b I_b + \overline{V}_c I_c \tag{A18}$$

(The bars over the V's in this equation denote conjugates.) A relation of this kind—one side of the equation may be multiplied by a constant, however—must be fulfilled if a fault is to be represented by a connection between the substitute networks. For, if the fault has no impedance, the vector power in the fault branch is zero; if connections are made between the networks, either directly or through ideal transformers, the total vector power leaving the networks at the points of connection is likewise zero.

The second general relation concerns the exclusion of zero-sequence current and voltage from networks A, B, C in accordance with equations $A4$ and $A8$. Consider the case of 2 simultaneous faults. Each of the networks A, B, C may be reduced to an equivalent T (figure 8), retaining the 2 points of fault and the ground or neutral point. These T's, like the equivalent T of the positive-sequence network, each contain 2 equivalent electromotive forces, denoted by E_x and E_y, equal to the voltage at the points of fault before occurrence of the faults. The following equations express relations between fault currents (I_x and I_y) and fault voltages (V_x and V_y) of each network:

$$E_{xA} - V_{xA} = (C_1 + S_1)\, I_{xA} + S_1 I_{yA} \tag{A19}$$

$$E_{xB} - V_{xB} = (C_1 + S_1)\, I_{xB} + S_1 I_{yB} \tag{A20}$$

$$E_{xC} - V_{xC} = (C_1 + S_1)\, I_{xC} + S_1 I_{yC} \tag{A21}$$

$$E_{yA} - V_{yA} = (D_1 + S_1)\, I_{yA} + S_1 I_{xA} \tag{A22}$$

$$E_{yB} - V_{yB} = (D_1 + S_1)\, I_{yB} + S_1 I_{xB} \tag{A23}$$

$$E_{yC} - V_{yC} = (D_1 + S_1)\, I_{yC} + S_1 I_{xC} \tag{A24}$$

where C_1, D_1, and S_1 are impedances of the equivalent T, which are the same for all 3 networks. Adding each group of three equations gives:

$$\Sigma E_x - \Sigma V_x = (C_1 + S_1)\Sigma I_x + S_1 \Sigma I_y \tag{A25}$$

$$\Sigma E_y - \Sigma V_y = (D_1 + S_1)\Sigma I_y + S_1 \Sigma I_x \tag{A26}$$

where

$$\Sigma E_x = E_{xA} + E_{xB} + E_{xC}$$
$$\Sigma I_x = I_{xA} + I_{xB} + I_{xC}, \text{ etc.}$$

Since the networks contain only balanced electromotive forces (or at least electromotive forces having no zero-sequence components), $\Sigma E_x = 0$ and $\Sigma E_y = 0$. Therefore, unless one of the impedances should be infinite, if $\Sigma I_x = 0$ and $\Sigma I_y = 0$, then it follows that $\Sigma V_x = 0$ and $\Sigma V_y = 0$; or, more generally, if either $\Sigma V_x = 0$ or $\Sigma I_x = 0$ and if either $\Sigma V_y = 0$ or $\Sigma I_y = 0$, then all 4 quantities, ΣV_x, ΣV_y, ΣI_x, and ΣI_y, are zero. Although the demonstration has been given for the case of 2 faults, similar demonstrations can be given for one fault, or for any number of faults. As a result of such demonstrations it may be reasoned that the connections representing a fault must be of such nature as to insure either that $\Sigma V = 0$ or that $\Sigma I = 0$; if either of these conditions is fulfilled at every fault (not necessarily the same condition at every fault), it follows that both $\Sigma V = 0$ and $\Sigma I = 0$ at all faults and hence also throughout networks A, B, C.

Any connection between the 4 substitute networks may be described by 4 equations. For the connections to correctly represent a given type of fault, 3 of the equations must be derived from the relations between phase currents and voltages for the fault in question (table I of reference 1); the fourth must be either $\Sigma V = 0$ or $\Sigma I = 0$. The connections for representing various single faults (figure 6) are proven correct as follows:

AG Fault

Relations of phase quantities: $V_a = 0, I_b = 0, I_c = 0$. Relations between substituted quantities satisfied by the connections:

$$V_A = V_D \qquad V_A + V_B + V_C = 0 \qquad I_B = I_C = I_A + I_D$$

Proof that the connections represent the fault: Since $V_A + V_B + V_C = 0$, it follows that $I_A + I_B + I_C = 0$. Substitute in the latter expression $I_C = I_B$ and $I_A = I_B - I_D$, obtaining $I_B - \frac{1}{3} I_D = 0$, or $I_b = 0$. By a similar process, obtain $I_C - \frac{1}{3} I_D = 0$, or $I_c = 0$. $V_A - V_D = 0$ is equivalent to $V_a = 0$.

BCG Fault

Relations of phase quantities: $I_a = 0, V_b = 0, V_c = 0$. Relations between substituted quantities satisfied by the connections:

$$-\frac{1}{2} V_A = V_B = V_C = V_D \text{ and } -2I_A + I_B + I_C + I_D = 0$$

Proof that the connections represent the fault: From the voltage relation, $-\frac{1}{2} V_A = V_B = V_C$, it may be shown that $V_A + V_B + V_C = 0$, from which it follows that $I_A + I_B + I_C = 0$. Subtracting $I_A + I_B + I_C = 0$ from $-2I_A + I_B + I_C + I_D = 0$ gives $-3I_A + I_D = 0$, or $I_A - \frac{1}{3} I_D = 0$, or $I_a = 0$. From $V_B = V_C = V_D$, we obtain $V_B - V_D = 0$ and $V_C - V_D = 0$, or $V_b = 0$ and $V_c = 0$.

BC Fault

Relations of phase quantities: $I_a = 0, I_b + I_c = 0, V_b = V_c$. Relations between substituted quantities satisfied by the connections: $V_B = V_C, I_B + I_C = 0, I_A = 0, I_D = 0$. Proof that the connections represent the fault: Since $I_D = 0$, $I_A - \frac{1}{3} I_D = 0$ or $I_a = 0$.

$$I_B + I_C = (I_B - \tfrac{1}{3} I_D) + (I_C - \tfrac{1}{3} I_D) = I_b + I_c = 0$$

Since $V_B = V_C$, $V_B - V_D = V_C - V_D$ or $V_b = V_c$. The connections also satisfy $I_A + I_B + I_C = 0$.

ABC Fault

Relations of phase quantities: $I_a + I_b + I_c = 0, V_a = V_b = V_c$. Relations satisfied by connections: $I_A + I_B + I_C = 0, I_D = 0, V_A = V_B = V_C$.

ABCG Fault

Relations of phase quantities: $V_a = V_b = V_c = 0$. Relations satisfied by connections: $V_A = V_B = V_C = V_D = 0$.

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Modern Trolley-Coach Operation

By JAMES H. POLHEMUS

Synopsis

This paper describes the operation of a modern trolley coach system. This system was installed one year ago with a single line and a few coaches. Now there are 7 lines in operation, the total route lengths exceeding 45 miles and requiring 40 coaches, each of which has a seating capacity of forty persons. The paper is generally divided into 2 parts, the first dealing with descriptions of the system and equipment, and the second part setting forth such experiences as have been gained in one year of operation.

ALTHOUGH there were earlier installations, the operation of modern trolley coaches may be said to date from 1928, when trolley coaches were put in operation in Salt Lake City. Systems were installed in more and more cities until today trolley coach operation is a factor in public transportation in 34 cities of the United States, not to mention the many European systems. It is the objective of this paper to discuss one of the most recently installed trolley coach systems, that of the Portland Traction Company in Portland, Oregon.

The Portland system consists of 45.5 miles of trolley coach line operating within the limits of the city and serving, together with 87.5 miles of street railway and 64.8 miles traversed by gasoline coaches, a population in excess of 300,000 people. Operation of trolley coaches started August 30, 1936, on the first line completed and additional lines were completed and put into operation until the contemplated program was consummated in May, 1937. The experiences throughout an over-all period of one year of operation are available although the completed system of 7 lines has been operating but 3 months. The system is now operating at the rate of about 385,000 coach miles per month and since the total mileage amounts to 3,300,000 coach miles in the 12 months of operation, the weighted average experience with this system amounts to about 8 or 9 months.

The overhead system is of the conventional 2-conductor type with the conductor tension at 3,000 pounds per conductor at 70 degrees Fahrenheit, with 100-foot spans in districts where coaches can operate at high speed. In the congested urban area, a tension of 2,000 pounds was used. The conductors are spaced 2 feet apart and the conductors nearest the curb are in general 12 feet from curb lines. A minimum clearance of 7 feet, 5 inches is maintained between inside conductors. The supporting structures are steel poles in the downtown areas and building pull-offs, if feasible, with wood poles in the outlying districts. The contact wire is 3/0 high-strength cadmium bronze alloy. On one of the 7 lines, the contact wire is round while wire on the remaining lines is grooved. Records are being kept to show the wearing ability of each, but it is yet too early to form even preliminary conclusions. The wire is lubricated with a light grade of mineral oil. The system operates with 600-volt direct current supplied by the affiliated Portland General Electric Company. Electric frogs of both shunt and series-operated type were installed and experience to date is in favor of the shunt type for system use as well as in the car barns. Porcelain strain insulators on pull-over wires have been found to be better than woodstick insulators when they can be located so that they will not be struck by a flying trolley. An interesting detail is that of passing tracks on which local coaches may draw up to the curb and allow express coaches to pass.

The Portland Traction Company now operates 140 trolley coaches over its 45 miles of trackless trolley routes. The coaches are 24 feet, $4^1/_2$ inches over bumpers, 104 inches extreme width, weigh 20,400 pounds, and have seats for 40 passengers. The normal peak load is 60 passengers but 100 passengers have been carried during times of extraordinary traffic congestion. The rear axle ratio of 9.97 and 42-inch wheels at a motor speed of 3,360 rpm develop the maximum speed of 42 miles per hour. The traffic regulations permit a maximum speed of 35 miles per hour, requiring a motor speed of 2,800 rpm. Coaches are equipped with air brakes on all 4 wheels, all glass is shatterproof, and the windshield is cleaned with 4 pneumatically operated windshield wipers. Doors are operated by air engines under control of the operator and the exit door is also controlled by foot treadles. Auxiliary circuits, such as lighting, buzzer, door control, marker, tail and head lights, horn, and ventilating fans, are supplied with power from a 12-volt storage battery and generator system. The principal reason for the use of the 12-volt circuit is safety of passengers. Another reason is to insure continuity of lighting while the coach is passing under insulated spacers. One of the most unusual features of these coaches is that each is driven by a single motor. The motor has a rolled-steel frame and weighs 1,050 pounds. It has a one-hour rating of 125 horsepower and the output when accelerating on a grade is 225 horsepower. Four interpoles and low voltage per commutator bar provide freedom from flashovers. Other motor characteristics at the hourly rating of 125 horsepower are 600 volts, 173 amperes, 2,420 rpm, and 120 degrees centigrade rise by resistance. The maximum allowable motor speed is 4,000 rpm. The motor is self-ventilated and without covers. Radio choke coils are inserted in the trolley

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circuits on the roof of each coach to prevent the operation of the coach from interfering with radio reception.

The street cars replaced by electric coaches were operated by one man and there is no saving in the operators' wages per vehicle hour, but the increased speed has reduced the cost of operators' pay per vehicle mile.

In July, 1937, the average speed of all vehicles in the Portland system was 11.35 miles an hour, which is an increase of 11 per cent over the July, 1936, average speed of 10.23 miles an hour. A part of this is due to an increase

of speed of gas busses from 13.11 miles an hour to 13.40 miles an hour. The average speed of street cars decreased 4 per cent from 9.63 to 9.26 miles an hour, due to some of the higher-speed car lines being converted to electric coach lines. The average speed of electric coaches is 12.78 miles an hour and this is an increase of 23 per cent from the 10.35 miles an hour average speed of the street car lines that were changed to electric coach. Unloading at both ends has decreased standing time and has increased the average speed. At heavy loading points double ended loading likewise increases the average speed.

The rate of acceleration of electric coaches is 3.5 miles per hour per second and this is twice the rate of acceleration of the street cars replaced by the coaches. The free-running speed of the street cars was 27 miles an hour and of the electric coaches, 42 miles an hour. The coaches are operating on city streets where the speed is limited by law and the maximum possible speed is never used.

Accidents have been caused in some cases where automobiles, closely followed by street cars, have made sudden stops with the result that the auto was rammed by the street car. Electric coaches stop as fast as or faster than do automobiles and do not ram the rear end of motor vehicles that have suddenly stopped, but, if passengers are standing, rapid deceleration may throw some elderly person to the floor. Operators with a standing load of passengers at times must make a choice between a collision with another vehicle and the possibility of personal injuries to standing passengers. Some automobile drivers do not realize the rapid rate of acceleration of the electric coach and after passing to the left of an accelerating coach, reduce speed, cut to the right in front of the coach, and a collision results. In August 1937, street cars ran 4,299 miles per accident, electric coaches, 5,133 miles, and motor coaches ran 9,379, miles. Motor coaches run a smaller percentage of their miles in heavy traffic than electric coaches and street cars and have a lower exposure to accidents than street cars and electric coaches. The ratio of miles to accidents for electric coaches is increasing as the operators have more experience in operating these vehicles.

With respect to maintenance, tires are not purchased but are rented on a mileage basis. Traction company employes change tires that are worn or flat and the tire company dismounts the tires from the rims. Tire pressure is maintained by the traction company. Front tires on the coaches on a line which has many curves were found to wear rapidly and on these tires the normal pressure of 75 pounds was increased to 85 pounds and the tread wear was reduced.

New tires are averaging about 23,000 miles and retreads about 17,000 miles, a total of 40,000 miles to a casing. In a few instances a casing is given a second retread, thus giving a casing with 2 retreads a total life of 57,000 miles.

Maintenance of electrical equipment is confined largely to cleaning contacts on controls and cleaning motors. The voltage and current regulators on the 12-volt lighting and door control system must be checked frequently as these regulators are subject to burning if the contacts are not kept clean.

Inspection of all movable parts is done on a regular schedule and in this way maintenance is reduced and there is a greater reliability of service

Maintenance of bodies is confined, as yet, to tightening of screws and bolts. All metal bodies are not in need of much maintenance in the first year of their life and, except for adjustments of brakes and door operating engines, but little work is done on the bodies.

Accidents are with us always and there are at all times coaches in the shops for repairs necessitated by collisions. Both electric and gas welding reclaim parts that at first sight appear to be fit only for junk. Quick drying lacquers cover the new work and soon the coach is again on the street.

Lubrication of the conductor wires is accomplished by means of a truck with trolley busses and trolley poles mounted on a frame on the truck. The upper end of each pole carries a lubricator that is essentially a tank containing a lubricant with a wheel that has its upper rim on the conductor and the lower rim in the lubricant. The conductors are lubricated every 1,500 shoe passes. Much work on the overhead was not completed when the coaches were placed in operation and until this has been done no regular inspection of the overhead will be made. Many poles and anchors were set in damp soil and it has been necessary to retension conductors and brail wires. Manufacturers have not, as yet, furnished a reliable and rugged overhead switching device to change the path of the shoe from the main line to a branch line or a turnout, but are working on this problem with great hopes.

Plans are now being made for a regular inspection of the overhead distribution system and this inspection should keep the overhead in good operating condition. Linemen who had worked on the single-trolley system had much to learn about protecting themselves and their equipment when working on 2 conductors of opposite polarity only 24 inches apart.

In considering operating costs, it must be remembered that this system has been and, in many particulars, still is in process of development. For example, several thousand dollars was spent in training operators, mechanics, and other employes, practically none of whom had had previous experience with trolley coaches and these development costs are included in the operating costs to date. With this qualification, some operating and statistical data are offered, all applying to the 12-month period immediately following operation of the first line.

Operating Expenses per Coach Mile

Power	3.23 cents
Conducting transportation expenses	8.80 cents
Traffic expenses	0.18 cents
General and miscellaneous expenses	2.48 cents
Total operation	14.69 cents
Maintenance of way and structures	1.02 cents
Maintenance of equipment	3.01 cents
Total operation and maintenance	18.72 cents
Provision for depreciation	4.47 cents
General taxes	0.94 cents
Bridge rentals	0.14 cents
Total operating expenses	24.27 cents
Operating ratio	93.70 per cent
Proportion of total operating expense assignable to pay-roll expense	46.0 per cent

These expenses are based upon the following statistics:

Total coach miles	3,288,647
Total coach hours	260,638
Total passengers carried	15,041,743
Total passengers per coach mile	4.57
Kilowatt-hours used per coach mile	4.04

In the 34 cities in the United States where electric coaches are in operation, the coaches ordinarily seat 40 passengers and have both single-motor and 2-motor propulsion with the present trend toward the single-motor equipment. The single motor uses more power than does the dual motor but the saving in weight and cost in favor of the single motor compensates for the greater power consumption. The average speed of electric coaches in Portland is in excess of that in cities of similar size, or larger, and in some cases is 18 per cent greater.

The installation of electric coaches is the largest ever made at any one time in the United States, both in number of coaches and in the miles of route. The entire trolley coach system, consisting of 140 coaches and 45.5 miles of route, was put in operation within 9 months.

In general, the installation of electric coaches in Portland has left no regrets. Minor problems have been met and most of them have been solved. Manufacturers have been called upon to replace parts and have done so at their own expense. Voltage regulators on the first coaches received were replaced. The mounting of the 12-volt generator was improved. Brake lining did not give the expected mileage and was replaced with a different type. The recommended clearance between brake blocks and brake drums was increased and brake block mileage was very greatly increased and scoring of brake drums eliminated. Considerable change was made in the motor control by one manufacturer and additional change is still desirable.

The tire manufacturer has altered the tread in the hope of obtaining greater mileage. While operators were being trained and were gaining experience, tires suffered, particularly on account of rear wheels striking curbs while rounding curves, but, with the "breaking-in" period concluded, this sort of unusual wear has been almost entirely checked, with a resulting decrease in sidewall and tread damage.

The springs in the trolley base are light for the duty they are called upon to perform and in the near future it will be necessary to replace these springs. The springs are probably being permanently deformed and the tension slowly decreases until there is but little room left for adjustment. Some trouble has been experienced with defective castings but the manufacturer has replaced these castings in the overhead system with a new design and

better workmanship. Coils in the electric frogs have failed for no apparent reason and we have hopes of a new design for the overhead switching.

With the first schedule on a line changed from street cars to electric coaches the speed was slow until the operators had experience in operating coaches. Men experienced in operating motor vehicles made better operators than those without driving experience. The operation of street cars helped in combating traffic problems but experience in steering a vehicle seemed to be very necessary.

Street cars carry 5.51 passengers per car mile, electric coaches 4.79 passengers per coach mile, and motor

coaches 2.86 passengers per coach mile. The street car lines with heaviest travel were not changed to coach lines and these lines still carry the heaviest loads. The condition of track and possibilities of rerouting determined the lines where street car service was replaced by coaches. Density of traffic determined whether electric coaches or motor coaches would be operated on the line under consideration. In the future, track will be repaired but when the time comes for replacing rail, the track will be covered with pavement and the cars replaced with coaches. Some of the remaining street car lines are in territory with sparse population and these lines will be replaced with motor coaches.

In conclusion, it may be said that public reaction to the operation of trolley coaches has been good. Revenues have increased from lines replacing street railways, but it is too early to determine the amount of traffic drawn from paralleling street railway lines and it is known that there has been a certain amount of such diversion, notwithstanding that the lines have been several blocks apart. Experience to date indicates that the overhead system is operating satisfactorily. The type of conductor is being tested for wear, and tests are also under way to determine the best lubricant and method of lubrication. In this connection, it may be added that automatic lubrication from passenger vehicles is being tried. Wear records for trolley shoes are maintained and tests of other details concerning the coaches, such as lubricants and lubrication, brake linings and drums, and brushes on motors and generators, are under way. Tire treads of various kinds are also being tested. With another year of experience to draw upon, some more definite facts and figures will be available.

Collaborating in the preparation of the above data were Mr. W. H. Lines, vice-president and general manager of Portland Traction Company, Mr. Gordon G. Steele, general superintendent, Mr. James P. Tretton, superintendent of equipment, and Mr. E. W. Moreland, statistician.

Engineering Curricula

IN AN ARTICLE entitled "What Should the Technical School Teach?" appearing in *Civil Engineering* for November 1937, pages 733–4, Scott B. Lilly, professor of civil engineering at Swarthmore College, asserted that "the great fear of the present executive is obsolescence—that some new process will develop which will make his whole plant valueless." Because of this fear many of the progressive companies are becoming ever more interested in the field of research. "Large companies maintain their own laboratories, while the small ones combine to form trade associations, hiring the best men they can find, and spending lavishly to discover new methods that will bring them added business."

Professor Lilly maintains that research has produced better materials, better manufacturing methods, and better design; moreover, it has affected the requirements for a four-year undergraduate course because of its demand for broader training. "The theory underlying a broad undergraduate training is that instead of trying to keep up with all the changes that are taking place in each field, a college should reduce the number of courses taught, do away with special curricula, and concentrate on the things it can do best. The time is still far distant when engineering will be all science. Many of the structures being built even today are standing not because the theory of design is absolutely correct, but because the computations result in a structure similar to one that has proved satisfactory. In some cases it may be years before theory catches up with practice. Nevertheless . . . colleges should teach the science of engineering—that is, . . . students should spend the major part of their four years on the underlying principles of engineering, devoting only a moderate amount of time to applications."

The author believes that teaching has been too much concerned with the formal processes involved. "Men have learned *how* to do things, rather than *why*. They learned rules. But would it not be better to teach all courses from the standpoint of developing principles? For years the student has asked why he must spend so much time on mathematics when practicing engineers have told him that they rarely, if ever, have occasion to use the calculus. He does not realize that he will use the type of reasoning he learned in the calculus, although unconscious of where he learned it. Mathematics, then, must be taught so that the principles remain, even though the formal processes, the rules, are forgotten."

A suggested new curriculum, designed to meet the demands of modern industry, would be identical for civil, mechanical, and electrical engineers for the first three years. "The courses would include mathematics, physics and chemistry, descriptive geometry, kinematics, mechanics (both analytic mechanics and strength of materials), electrodynamics, hydraulics, and thermodynamics. This work would occupy three-quarters of the student's time for the first three years. In the senior year, he would be allowed to specialize in that branch of engineering in which he is most interested. He would have had the basic courses in all three fields and could take any advanced course offered. Some attempt should be made in at least one of these selected courses to carry the man as far as he is able to go—to acquaint him with the frontiers of knowledge in that field, so that he can see that engineering is not a dead thing, but a living, growing profession that will demand his best efforts."

"The broad engineering education . . . must include courses that cover the human side as well as the material side of the profession. But a 'course' in college is not an end; if it fails to develop a keen desire to know more, to go into the subject more deeply, it may be worse than useless . . . The greater part of this kind of education must come after graduation — and this will be true no matter how many courses were taken in college. The most important thing, therefore, is to instill the desire to be well read and well informed, not as a window dressing, but as equipment to face social problems and do something about them."

Stray-Load Losses of D-C Machines

By E. W. SCHILLING
MEMBER AIEE

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Synopsis

This article describes a method of measuring stray-load losses which is readily adaptable to the test departments of the manufacturers. Usually no additional test apparatus will be required beyond that already available. The same arrangement used for a pump-back heat-run test is used with only slight modification. Experimental data are given showing the effect of speed, load, and field strength upon these losses.

STRAY-LOAD losses may be defined as the losses at any particular load which are not accounted for by the conventional methods of measuring and calculating losses. They are divided into 3 classifications according to the causes producing them, as follows[1]:

1. Loss due to eddy currents in the armature conductors.
2. Short-circuit loss of commutation.
3. Increased core loss caused by distortion of the main field by armature reaction.

Various methods have been proposed for taking these losses into account. It has been suggested that the no-load core losses plus armature I^2R losses be multiplied by a constant whose value should be somewhere between 1.1 and 1.5.[2,3] Such a procedure is open to the criticism that it would require a great number of constants to take into account differences in design.[2]

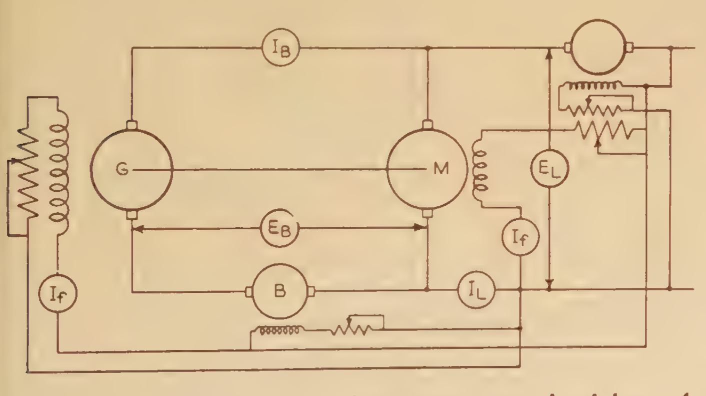

Figure 1. Circuit used in determining stray-load loss of the set. Rotational losses supplied electrically

Input-output tests have been made and data published.[2,4] The results of these tests were contradictory. One paper indicated high accuracy to be possible, whereas the other indicated that the method is not dependable.

Some work has been done on this problem[5] by using a generator with a compensating winding in the pole faces and comparing no-load losses with this winding unexcited to those when it is separately excited to various percentages of normal value. Of course, the first objection to this method is that most d-c machines do not have compensating windings. A further objection is that the additional loss determined in this manner is the result of field distortion and does not include losses in the armature conductors themselves due to eddy currents.

There is at present no standard way of directly measuring these losses, and according to the American Standards for Rotating Machines they are to be taken as one per cent of the output. This rule obviously makes no provision for differences in design and, in the case of adjustable-speed motors, charges the same loss to the machine at weak field and high speed as at strong field and low speed. That the latter is objectionable is clearly shown by the data given in this paper.

As a means of measuring stray-load losses, a direct measurement of total losses of 2 machines connected together in a modification of the familiar pump-back connection as shown in figure 1 is proposed. By subtracting the determinable losses from the total measured losses the total stray-load loss of the two is determined.

One of the contributions made by this paper is a method of allocating the proper proportion of the total stray loss to each machine when using the method described above; the other is informational in nature, that is, data are given on the stray loss resulting from operating d-c motors under varying conditions of speed, load, and field strength.

Test Procedure

The circuit used for making the tests is shown in figure 1. M and G are machines of the same size, type, and design, and the brushes of both are set on neutral. They are therefore considered identical. Throughout any given test the field currents of the 2 machines were kept constant. The armature currents were varied by changing the booster (B) voltage.

The combined losses of the 2 machines M and G are

$$E_L I_L + E_B I_B = L_t$$

L_t includes the armature I^2R loss, commutating-pole-winding I^2R loss, no-load core loss, brush-contact loss, windage and friction loss, and stray-load loss.

A paper recommended for publication by the AIEE committee on electrical machinery. Manuscript submitted April 22, 1937; released for publication October 8, 1937.

E. W. SCHILLING is associate professor of electrical engineering at Michigan College of Mining and Technology, Houghton, and R. W. KOOPMAN is assistant professor of electrical engineering at the University of Kansas, Lawrence. The authors are indebted to Mr. Scott Hancock, manager of the industrial motor engineering department of the Westinghouse Electric & Manufacturing Company, and to Professor G. W. Swenson, head of the department of electrical engineering of the Michigan College of Mining and Technology, for suggestions and information relative to this work.

1. For all numbered references, see list at end of paper.

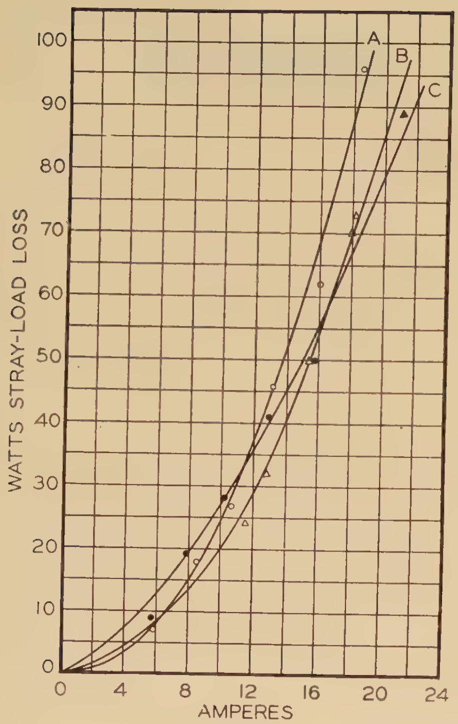

Figure 2. Stray-load loss of set at 850 rpm, using circuit of figure 1, versus average armature current of the 2 machines

A—Field current 0.50 ampere

B—Field current 0.66 ampere

C—Field current 0.80 ampere

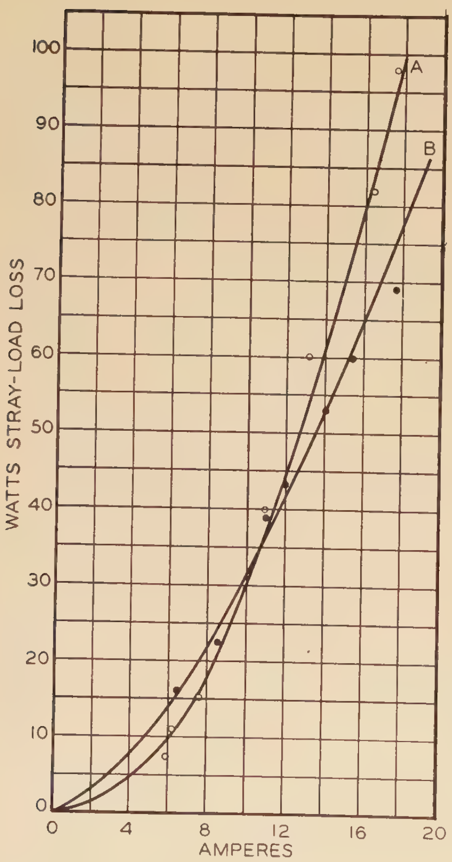

Figure 3. Stray-load loss of set at 1,000 rpm using circuit of figure 1

A—Field current 0.50 ampere

B—Field current 0.80 ampere

In order to insure that the various friction losses, the I^2R losses, and, to a limited extent, the core loss would remain constant during the period required for taking the readings, it was necessary to run the machines until constant temperatures were reached. After this temperature was reached the brush contact drop was measured. Next the electrical input readings of E_L, I_L, E_B, and I_B were taken. Immediately the line was opened, disconnecting the machine on the right; under this condition, the coupled machines come to rest, but the booster continues to circulate current of very nearly the same value as when all machines were in motion.

This convenience was of great value because the drops across the commutators and series resistances could be measured with very little loss of time and, consequently, with very little change in resistance between the time the input readings were taken and the time the resistance measurements were taken. As soon as the resistance measurements were completed the set was started again and run at the same value of armature current as before, in order that the temperatures would remain constant. The internal voltages of motor and generator were then computed. The field current of the motor was then changed to

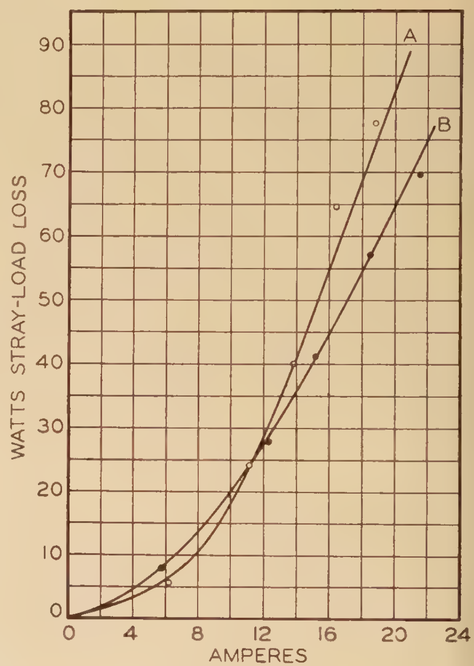

Figure 4. Stray-load loss of set at 780 rpm, using circuit of figure 1

A—Field current 0.50 ampere

B—Field current 0.80 ampere

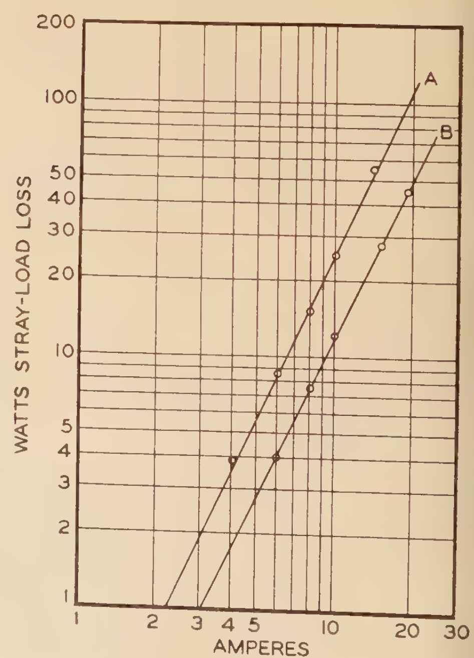

Figure 5. Determination of exponent n at 850 rpm, 0.50-ampere field

A—Loss versus average armature current of the 2 machines of set using circuit of figure 1

B—Loss versus armature current of one machine; losses separated according to scheme proposed

correspond to this voltage as read from the saturation curve, the booster circuit was opened, and the generator field current was adjusted to give the calculated internal voltage. The friction, windage, and core loss of the set could then be determined from the input to M and its calculated I^2R and brush-contact losses.

By taking the core-and-friction-loss readings immediately after each test, errors that result from wearing of brushes and from changes in bearing friction due to temperature changes were eliminated.

The stray-load loss of the set L_s was taken to be L_t minus brush contact loss minus I^2R loss minus friction, windage, and core loss. A series of load-loss readings was thus taken at constant field current and speed for several values of I_G. These losses were then plotted against the average current of the 2 machines. Several different series of readings were taken using different speeds or field currents; these results are shown in figures 2, 3, and 4.

Determination of Portion of L_s Due to Each Machine

The curves mentioned above show how the total load loss of the set varies with average armature current, but do not give that due to each machine, because the armature currents are different.

We shall now describe the method used to separate L_s into the components due to each machine.

Since we assume that the 2 machines are identical, and since they operate at equal field currents, the only variable affecting L_s is the armature current. If the law of variation of L_s with armature current were known it would be mathematically possible to calculate the portion of L_s to be charged to each machine. Plotting L_s versus average armature current gives us some idea of this law.

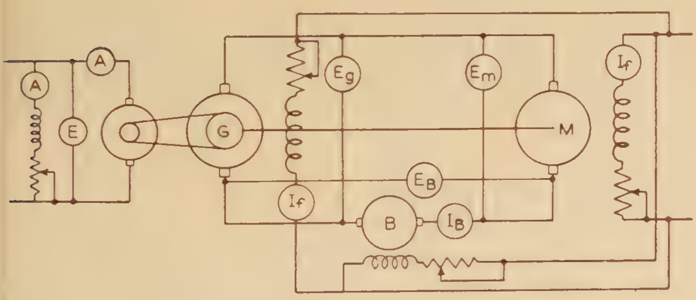

Figure 6. Circuit for obtaining stray-load loss with same armature current in both machines

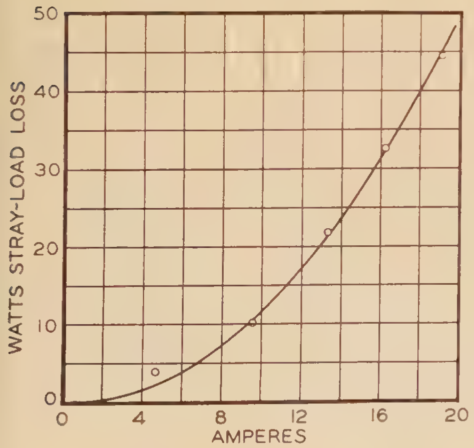

Figure 7. Stray-load loss of one machine at 850 rpm, 0.50-ampere field, versus armature current. Curve calculated from test data obtained using circuit of figure 1. Circles represent test points obtained by using circuit of figure 6

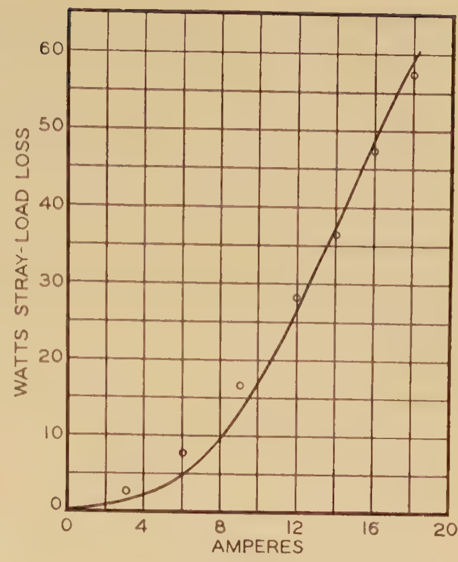

Figure 8. Same as figure 7 but for 1,000 rpm, 0.50-ampere field

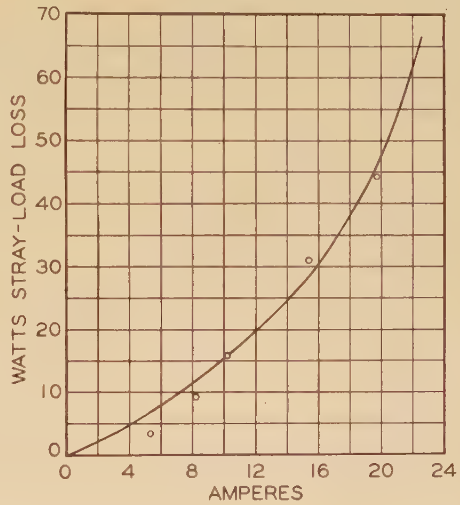

Figure 9. Same as figure 7, but for 1,000 rpm, 0.80-ampere field

Assuming that these curves can be expressed by $L_s = kI_a^n$ we can easily find n by plotting on logarithmic paper as shown in figure 5A. Then at a particular value of L_s,

$$L_s = kI_G^n + kI_M^n$$

and the portions of L_s chargeable to generator and motor respectively are

$$L_s \frac{I_G^n}{I_M^n + I_G^n} \quad \text{and} \quad L_s \frac{I_M^n}{I_M^n + I_G^n}$$

to the degree of approximation that n approximates the true value of n as it would be obtained by plotting the actual load loss of only one machine against its armature current.

Theoretically we could plot a curve of the load loss of one machine as obtained by using the approximate value of n and obtain a new value of n, make a new separation, plot another curve, etc., until we approach the true value of n as closely as we please. Practically, however, it is

necessary to make only one separation. That is shown in figure 5, where curve A is the plot of L_s versus average armature current and B is the curve of the load loss of one machine plotted versus its armature current. There is scarcely any difference in the slopes of the 2 curves. The closeness with which the points fit the straight lines indicates that the equation $L_s = kI_a^n$ is correct to a high degree of accuracy.

In order to illustrate the method more clearly an example of a typical set of readings at 850 rpm and 0.5 amperes field is given.

E_L = 94.80 volts
I_L = 4.42 amperes
E_B = 18.70 volts
I_B = 11.05 amperes

Generator brush contact drop (positive + negative)	= 1.40 volts
Motor brush contact drop (positive + negative)	= 1.80 volts
Generator armature current, I_G	= 11.05 amperes
Motor armature current I_M	= 15.47 amperes
Resistance of generator windings at operating temperature plus series resistance of 0.017 ohm	= 0.807 ohm
Resistance of motor windings at operating temperature plus series resistance of 0.012 ohm	= 0.847 ohm
A. Line supply watts	= 419 watts
B. Booster supply watts	= 206.6 watts
C. Total supply watts	= 625.6 watts
D. I^2R generator	= 98.8 watts
E. I^2R motor	= 203.0 watts
F. Brush-contact loss, generator	= 15.5 watts
G. Brush-contact loss, motor	= 27.9 watts
H. Core loss, friction, and windage of set	= 234.0 watts
I. Total of directly measurable losses ($D + E + F + G + H$)	= 579.2 watts
J. Stray-load loss L_s = C − I	= 46.4 watts

Determination of L_s Chargeable to Each Machine

From figure 5A, $n = 2.16$. Therefore the portion of L_s chargeable to the generator is

$$46.4 \frac{\overline{11.05}^{2\cdot16}}{\overline{11.05}^{2\cdot16} + \overline{15.47}^{2\cdot16}} = 46.4 \frac{179.35}{550.35} = 15.1 \text{ watts}$$

and that chargeable to the motor is 46.4 − 15.1 = 31.3 watts.

Check on Procedure

As a check on the validity of the method which was used to separate losses, another series of tests was run on the set under the same conditions of speed and field current as before; but in this series the circuit of figure 6, in which the armature currents of the two were exactly the same, was used. In this test as in the other the same precautions regarding heating were observed. It was again possible to use the booster to circulate current for measuring IR drops and thus save time, as no extra connections had to be made. The driving motor at the left in figure 6 was supplied from a variable-voltage generator. This voltage was reduced to a low value, and the field circuit of the motor opened. This stopped the set but still circulated current through the armature of the driving motor and thus simplified the measurement of resistance in this machine. The stray-load loss of the set is then equal to the booster output minus calculated losses of the set plus increased output of the driving motor between no current in the set and that current at which the test was run. Brush-contact drops were measured on all machines and these values used in calculating the brush-contact losses.

The stray-load loss under these conditions of operation should be the same for each machine. Figures 7, 8, and 9 were plotted from data obtained by applying the method of separation described in this paper to the curves of figures 2A, 3A, and 4B. The circles are test points obtained by using the circuit of figure 6. Here then are the results of obtaining the stray-load loss of a machine from 2 entirely independent and different tests. The results check as closely as could ever be expected in a test of this kind.

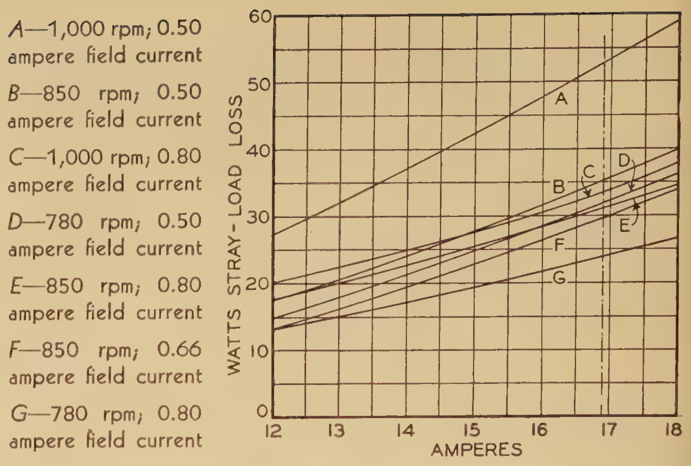

Figure 10. Comparison of stray-load loss under different conditions of speed and field current

Conclusions

In these tests a machine operating under different conditions of speed and field current shows a wide variation in load loss, as shown in figure 10. The broken vertical line indicates rated full-load current. The outputs of the machine are approximately the same at 1,000 rpm, 0.5 amperes field; 850 rpm, 0.66 ampere field; and 780 rpm, 0.80 ampere field, but the stray-load losses vary widely between these limits. This shows the need of a new rule for calculating stray-load loss for adjustable speed machines, as the present rule would charge the same loss at all three speeds. Another illustration of the inadequacy of the present rule is shown by figure 10. For instance, B and C intersect at about 14.8 amperes. The data given in this paper show that the load losses are equal at these intersections; yet the outputs are different in that they correspond to a speed of 850 rpm and field of 0.5 amperes for B and a speed of 1,000 rpm and field of 0.8 amperes for C. The present rule would charge different load losses for the 2 conditions.

All the curves taken with weak field show steeper slopes in the region of high armature current than those taken with the stronger field. The reason for this difference is that the armature current has a greater distorting effect on the resultant field when the main field is weak.

The advantage of using this method over the input-output test is that losses are measured directly, whereas in the input-output test they are taken as the difference between two relatively large quantities. The improvement in accuracy is obvious.

Another advantage is that very little wiring is required beyond that for the pump-back heat-run test as it is set up by many manufacturing companies. No special equipment is needed, and the labor required is comparatively low.

Its disadvantage is that the machines must be assumed to be identical.

The losses obtained were higher than expected, probably because the air gap was shorter than the average. This in itself is another fact which indicates the necessity of adopting a test procedure for determining stray-load loss.

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The Library as an Engineering Tool

LITTLE excuse exists for those engineers who fail to furnish the correct answer to a current problem if it can be deduced, at least in part, from information available in libraries, according to an article by Gregory M. Dexter appearing in the November 1937 issue of *Mechanical Engineering*, pages 845–9. The author believes a library to be an engineering tool worthy of more than passing thought, because "some [engineers] find it easy to go along in the daily job without sensing or taking time to study the implications of new developments in unrelated or even in related fields of their daily activity. When suggestions are made for improved methods, many of them at some time say, 'it cannot be done.' They have not had sufficient interest or leisure to find out whether conditions have changed, new developments have occurred, or the previous failure did not arise from some fault in management or application of method."

Many engineering problems are settled easily by reference to the latest books; consequently, one of the most valuable source books for the engineer is the catalog of the large publisher of technical books. Yet often he will find that the best book on a particular subject is not published by one of the large technical publishing houses, and if he is thorough in his search for knowledge, he may find that the book he wants can be obtained only from some publisher of whom he has never heard.

"Many problems which engineers have to solve are so involved in technicalities, so unusual, or so special in application that no book available gives more than an elementary discussion. Places to which an engineer may turn then are the various departments of the federal and state governments as well as the numerous experiment stations.

"He should have always available a complete set of the indexes of federal publications which are obtainable from the Superintendent of Documents, Washington, D. C. . . . If the particular subject in which he is interested is not listed, a letter to the appropriate federal department often will bring him valuable information on unpublished data or other suggestions."

The author admonishes the reader that the titles to some of the general indexes are likely to deceive the engineer concerning their actual scope, and that valuable information sometimes may be obtained from the most unlikely appearing sources.

"Services of a librarian often are used in making searches for engineers. No disparagement of the value of such services is intended . . . . but engineers should recognize how much better results could be obtained by an engineer instead of a librarian. The engineer appreciates all ramifications of the problem he is investigating. He needs, of course, the facility a librarian has in knowing how to use a library. He needs persistence and imagination. Yet an engineer who knows his subject and has those qualities plus some knowledge of the library undoubtedly could do a better job of searching than a librarian. Merely glancing over an article would tell him whether it was worth abstracting or only listing in his bibliography.

"No engineer should entertain the idea that a library search is a method of avoiding original thinking. It is only a method of avoiding unnecessary expense in repeating mistakes that other men have made. It is a way of trying to start with new designs, inventions, or developments where other engineers and inventors have stopped."

The article contains comprehensive listings of book catalogs and indexes, government publications, guides and indexes to economic data, and general and special indexes. Most libraries have special bibliographic facilities of their own which should not be overlooked, and the author suggests ways of obtaining and using these special facilities.

Oil Oxidation in Impregnated Paper

By J. B. WHITEHEAD
FELLOW AIEE

T. B. JONES
ENROLLED STUDENT

Introduction

MUCH HAS BEEN written recently on the influence of oil oxidation on the properties and stability of impregnated paper insulation. It is thought by many to be a principal cause of deterioration in high voltage cables. Oxygen is highly soluble in cable oils; if present in appreciable quantity and at moderate temperature elevation, the oils oxidize rapidly with consequent loss of insulating value. However, the amount of oxygen remaining in a carefully dried paper cable is so small, and the oxidation process is so slow that it remains to be proved that it is more important in deterioration than other well-known causes.

In this paper we report a series of studies of the oxidation process in cable paper impregnated with oil containing different amounts of oxygen, as indicated by changes in well-known electrical quantities. Separate studies of the effect of equal amounts of air and of nitrogen, and of the behavior of the oil alone, and as affected by paper and metal, throw interesting light on the nature of the progressive changes found in the electrical characteristics.

Experimental Method

One type of oil and one type of paper were used throughout. Ten layers of the paper were assembled in a small parallel-plate capacitor, equipped with the usual guards, and mounted in a Pyrex glass dish, and placed inside an evacuating and impregnating tank with temperature control. See figure 1. The paper is evacuated at 0.05 millimeter of mercury pressure to a standard degree of dryness and the oil admitted for impregnation. Before admission the oil is filtered, degassed, and saturated with oxygen at various pressures, and impregnation takes place in an atmosphere of oxygen at the same pressure. After impregnation the sample is kept at the same constant pressure and at a temperature of 80 degrees centigrade for about one week. Measurements of power factor and capacitance, as related to voltage and temperature (at end of test) were made at intervals. At the end of the run the power factor of the individual paper layers, and the electrical properties of the oil drained off the specimen, were measured. Additional studies were made on the oil alone and on the impregnated paper using nitrogen as impregnating atmosphere. The catalytic effect of several metals on oil oxidation was also measured.

A paper recommended for publication by the AIEE committee on research. Manuscript submitted September 16, 1937; released for publication October 15, 1937.

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1. For all numbered references, see list at end of paper.

The Paper and the Oil. A single grade of uncalendered chemical wood pulp "kraft" paper, as made by a well known manufacturer was used throughout. Its properties[1,20,21] are given in table I.

The oil, designated by the refiner as "highly refined paraffin" cable oil, was delivered protected by nitrogen atmosphere and so maintained until used. Its properties are given in table II.

Test Capacitor. The capacitor is of circular parallel-plate type; high-voltage electrode 13-centimeter diameter, low-voltage electrode 10.4-centimeter diameter, equipped with guard ring, radial width of gap and ring 1.25 centimeters; material, brass throughout.

Ten circular sheets of paper 15.6-centimeter diameter constituted the usual test sample. A constant weight was placed on the upper high-voltage elect ode to ensure uniform pressure in all samples; air capacitance at this separation, 71 micromicrofarad . The capacitor is mounted in a shallow Pyrex glass dish, which is placed in a vacuum-tight, temperature-controlled impregnating tank shown in figure 1. The tank can be evacuated to 0.05 millimeter of mercury, and heated to 110 degrees centigrade. The oil is admitted through Pyrex tubing, and the removable top

Table I. Physical and Electrical Properties of the Paper

Thickness	0.0045 inch
Diameter	6.00 inches
Specific gravity	0.882
Gurley air resistance	640 seconds
Effective capillary radius	8.2×10^{-6} centimeter
Conductivity	1.0×10^{-15} mho per cubic centimeter
Power factor	0.00140
Dielectric constant	2.41

Electrical measurements at 80 degrees centigrade

Table II. Physical and Electrical Properties of the Oil

Pour point	4.4 degrees centigrade
Flash point	263 degrees centigrade
Specific gravity	0.903
Viscosity	4.07 poises
Surface tension	38.3 dynes per centimeter
Penetrative power	6.52×10^{-3}
Dielectric strength	28,820 volts
Conductivity (20 minute)	5.75×10^{-14} mho per cubic centimeter
Power factor	0.0005
Dielectric constant	2.204

Measurements at 40 degrees centigrade

Table III

Pressure of Oxygen	Volume of Gas Absorbed	Per Cent of Oil Volume
1 millimeter	0.13 cubic centimeter	0.013 per cent
5 centimeter	7.00 cubic centimeter	0.7
10 centimeter	14.00 cubic centimeter	1.4
76 centimeter	104.00 cubic centimeter	10.4

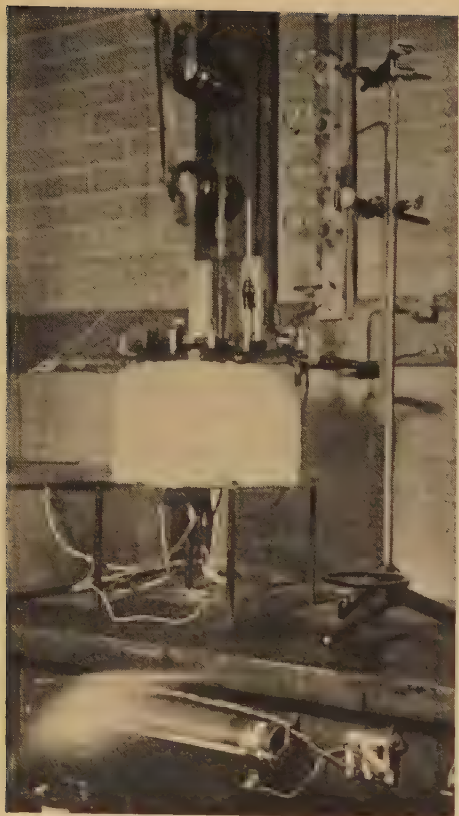


Figure 1. The test cell

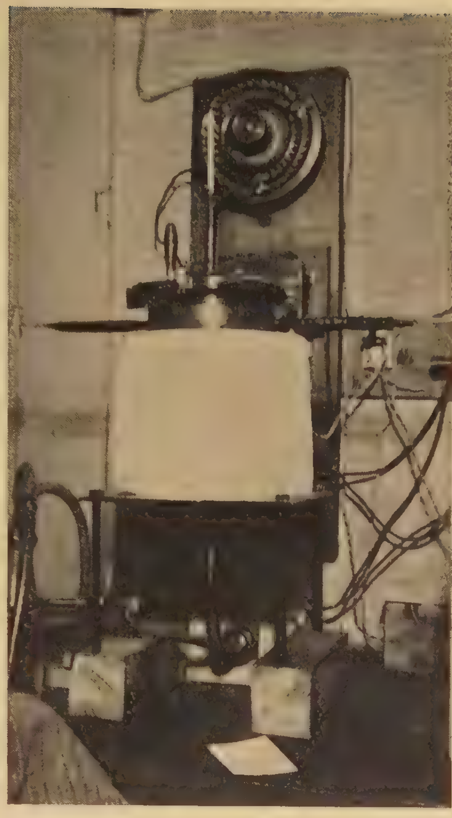


Figure 2. The oil filter cell

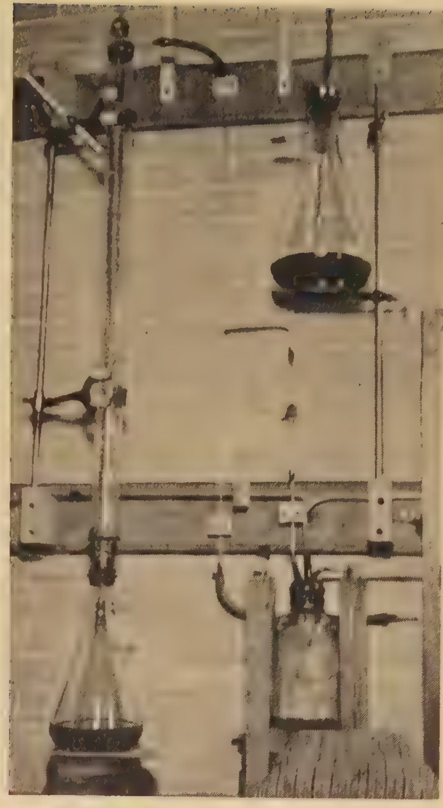


Figure 3. The degasification and dehydration apparatus

carries glass bushings for the electrical connections.

Oil Purification and Oxidation. The oil as received is first passed through the glass wool filter shown in figure 2, and then through the combined vacuum degasifier and dehydrater shown in figure 3. In the latter the oil passes down in a thin film over the turns of an open spiral of Nichrome wire in the inner of 2 coaxial glass tubes. The outer tube contains a heating coil; temperature in operation 80 degrees centigrade, pressure, 0.2 millimeter of mercury. After this treatment the oil had a power factor (60 cycles) of 0.0003 and a breakdown strength (standard disk gap) of 30,000 volts at room temperature.

Oxygen Content of Oil. Oxygen was admitted to the oil in different amounts, by exposing it to the gas at different pressures, in the apparatus shown in figure 4.

Figure 4. The oxidation apparatus

It has been shown that the volume absorbed-pressure relation is linear over a wide range,[22] for equal times and temperatures of exposure. In this work the oil was first raised to a temperature of 80 degrees centigrade, and evacuated to 0.1 millimeter of mercury. Then dry oxygen was admitted and the sample allowed to absorb oxygen for a period of 65 hours at constant pressure. The values of pressure adopted for study were 1 millimeter, 5 centimeters, 10 centimeters, and 76 centimeters of mercury. In what follows the different samples will be referred to in terms of these pressure values. The amount of oxygen absorbed in the several 1,000-cubic-centimeter samples at the respective pressures was found to be as given in table III. It will be seen that the relation between pressure and volume absorbed is approximately linear.

Impregnation. The test electrodes were washed in successive baths of soap and water, benzine, alcohol, or carbon tetrachloride, and distilled water, and dried. Ten layers of paper were placed between the plates and the whole placed in the impregnating and measuring tank. The temperature was raised to 105 degrees centigrade, and the pressure reduced to 0.1 millimeter of mercury. Frequent measurements of power factor and conductivity were taken in order to follow the drying process. Constant values indicating extreme state of dryness were usually reached in 72 hours; power factor, 0.00140; conductivity 1.0×10^{-15} mhos per cubic centimeter. When these values were reached the temperature was lowered to 80 degrees centigrade and the oil, after treatment as already described, was admitted for impregnation.

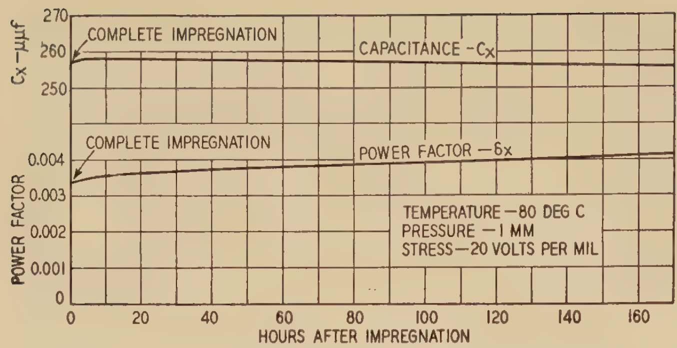


Figure 5. Power factor and capacitance versus time

In each case impregnation took place in an atmosphere of oxygen and at the same pressure and temperature at which the oil had been saturated. Thus for the 5-centimeter test the oil was preoxidized at 5 centimeters of mercury pressure and 80 degrees centigrade, and admitted to the dry paper at the same pressure and so maintained. The glass dish containing the capacitor was filled with oil and so remained throughout the test, so that there was a constant supply of oil and gas at constant pressure throughout the test. After admission of the oil the sample was allowed to stand for 24 hours to ensure complete impregnation. In the results reported below the end of this 24 hours is taken as *zero* time. Thus at this stage the oil had already been exposed to oxygen at 80 degrees centigrade during gas saturation, and paper impregnation, for a total of 89 hours. Electrical measurements were begun at this point, and consisted of power factor and capacitance at 60 cycles, and 20 volts per mil of paper thickness, 3 times a day; and a power factor-voltage run up to 150 volts per mil once each day. This program was followed for 168 hours, the duration of the normal test.

After the normal test, heat was removed from the tank (pressure constant) and during cooling the power factor-temperature curve of the sample taken for the range 80 degrees–25 degrees centigrade; a power factor-voltage curve was then taken at room temperature. The oil was drained from the sample for further test; the sample was then disassembled and consecutive measurements made of the power factor of each layer; the successive layers were carefully examined for any evidence of gas spaces, wax formation, or other significant condition.

At no time during the above tests was sustained voltage applied to the samples, and the electrical measurements 3 times a day were of brief duration and at low stresses. Thus the various behavior of the samples, as observed, is due to the oxidation process alone.

Electrical Measurements. Power factor and capacitance were measured on the transformer bridge developed in these laboratories by Seletzky[31] and McCurley.[24] It has a power factor accuracy of 0.0001 and can be balanced in less than 3 minutes. It lends itself readily to variations of setting needed for ranges of voltage stress, and for tests on single paper layers. The standard air capacitor is of flat type with electrodes 14 by 28 inches; the capacitance is 179 micromicrofarad. The output transformer feeds into a resistance-capacitance coupled amplifier. The detector is a vibration galvanometer; sensitivity, 40 millimeters deflection per microampere, at one meter distance of scale. A high sensitivity d'Arsonval galvanometer was used for d-c conductivity measurements, under methods described in earlier papers.[1]

Experimental Results

Five series of observations were made of the influence of oil-absorbed oxygen on the behavior of impregnated paper. These will be referred to as the 1-millimeter, 5-centimeter, 10-centimeter, and 76-centimeter tests for pure oxygen. The fifth series covers a sample with oil treated at one millimeter *air* and impregnated and tested at one millimeter *air*, the process being identical in all other respects with the one-millimeter oxygen test.

One-Millimeter Oxygen Test. The results are shown in figures 5, 6, 7, 8, and 9. The capacitance, figure 5, is constant over the 168 hours of the test. The power factor rises very slightly from 0.0038 to 0.0042.

The power factor-voltage relations taken at 24-hour intervals are indicated in figure 7, and the resulting ionization factors in figure 6. The power factor-voltage curves at 80 degrees show a rising tendency at first, but evidently indicate an approach to a maximum value of

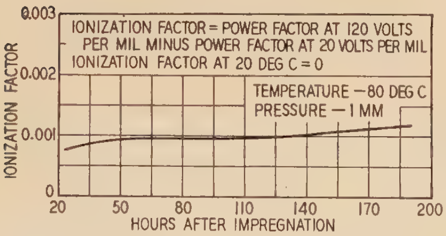


Figure 6. Ionization factor-time

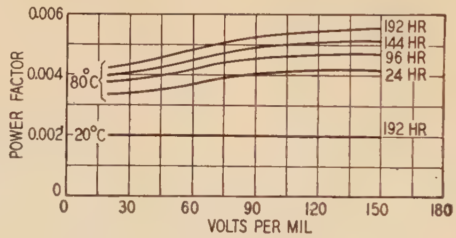


Figure 7. Power factor-voltage

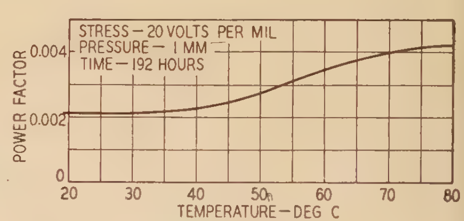


Figure 8. Power factor-temperature

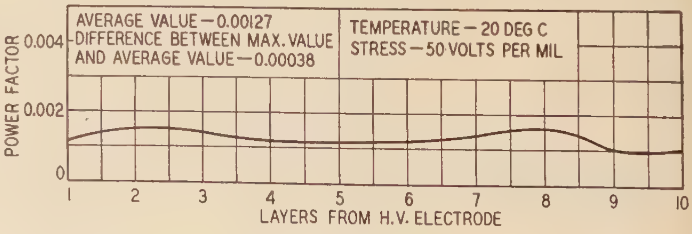


Figure 9. Layer variation of power factor

power factor. This behavior has been noted in earlier[1] studies of well-impregnated samples, although at lower stresses. The power factor at 20 degrees is constant between 20 and 150 volts per mil. These facts indicate the relative unimportance of gaseous ionization and suggest the presence of some type of oil ionization increasing with temperature and time, and voltage, up to a certain value. The increase with temperature, figure 8, is due to the increased mobility of the liquid ions; the increase with time to the increase of the number of ions with progressive oxidation or other cause; the increase with voltage is due to either increased mobilities, or new ions formed under increased stress, due to collision or other cause. The maximum of power factor results from a maximum conduction current when all ions are withdrawn as fast as formed. Other evidence in support of this view is given hereinafter. Other suggestions of mechanisms of the formation of new liquid ions are those of Inge and Walther[7] and Arman and Starr.[25]

Figure 9 shows the variation of power factor between successive paper layers. It is seen that the power factor is fairly uniform from layer to layer throughout and of a very low average value. The maximum variation is only 0.0006 power factor. The maximum of power factor occurs in the eighth layer from the high voltage electrode, and not at the layers adjacent to electrodes as frequently observed. Indeed, at the electrodes the power factor is at its lowest values, indicating that at the low oxygen content here in question, the electrode-oil reaction does not appear within a period of 200 hours at 80 degrees centigrade. Apparently, therefore maxima of power factor in layers adjacent to conductor and sheath sometimes observed in new cables are due to some other cause.

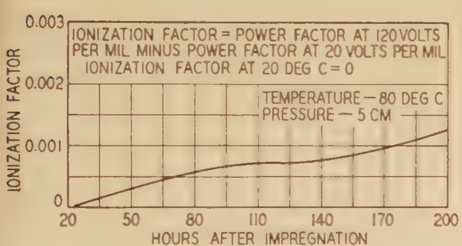


Figure 11. Ionization factor-time

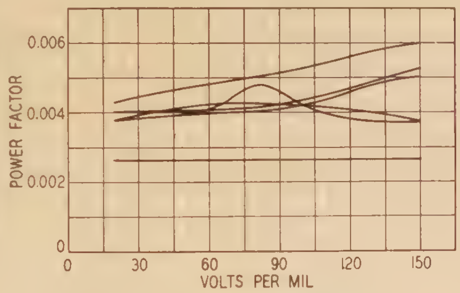


Figure 12. Power factor-voltage

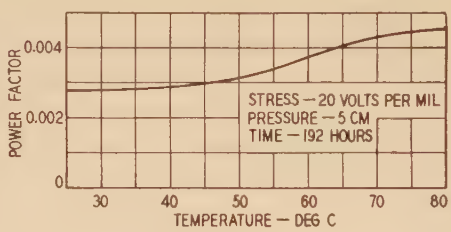


Figure 13. Power factor-temperature

5-Centimeter Oxygen Test. The results are shown in figures 10, 11, 12, 13, and 14. The capacitance-time, and power factor-time curves, figure 10, are closely the same as in the one-millimeter test, with a somewhat increased rising tendency in the latter beyond 120 hours. This indicates that the 50-fold increase in oxygen content has a scarcely noticeable effect on these curves. The power factor-voltage curves, also, figure 12, except for some irregularity in the early stages, are substantially flat at 80 degrees up to about 100 hours, and do not rise above those of the one-millimeter sample until the end of the test, where the maximum value at 150 volts per mil is only 0.006. At 22 degrees the curve is definitely flat up to 150 volts per mil, at 0.0026 power factor; this is slightly higher than the corresponding curve, 0.002, at one millimeter, due probably to the increased oxidation. This, however, has little or no effect on the ionization characteristics, see figure 11. In fact up to 120 hours at 80 degrees centigrade, the electrical properties of this sample are substantially the same as those of the sample containing only one-fiftieth as much oxygen, and only slightly impaired beyond. The layer-power factor curve indicates the beginning of catalytic action of the brass electrodes.

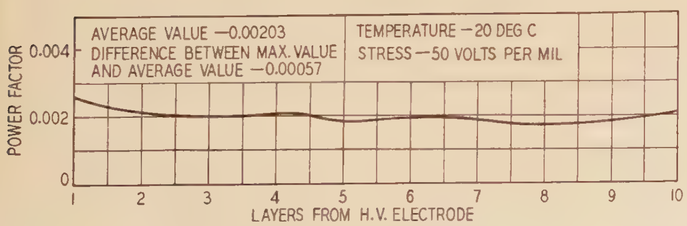


Figure 14. Layer variation of power factor

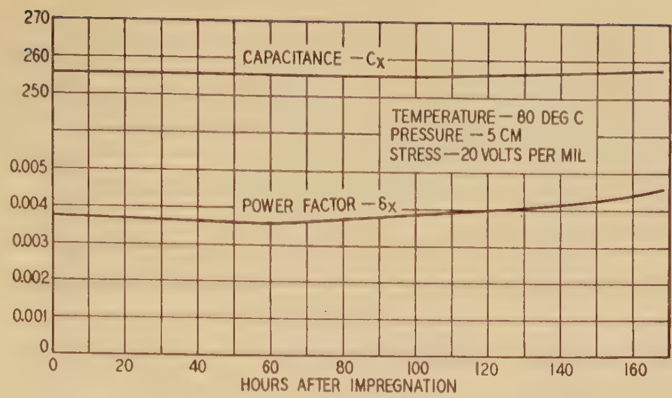


Figure 10. Power factor and capacitance versus time

These facts suggest that the deteriorating effects of small amounts of oxygen are either negligible or very long delayed in good cable insulation in normal service; also that a substantial amount of oxygen might be present in new cable, and not show itself for sometime.

Tests at 10 Centimeters and 76 Centimeters of Mercury Pressure Oxygen Content. In order to accelerate the oxidation process still further, similar tests at much greater values of oxygen content were made, that is, the oil was saturated with oxygen at 10 centimeters and 76 centimeters of mercury pressures, respectively. The results are shown in figures 15 to 19, respectively in which

the results at lower pressures are also included for convenient comparison.

Figure 15 shows the power factor plotted against oxygen content, as indicated by saturation pressure, for four different periods of time at 80 degrees centigrade after impregnation. Each curve thus represents an increased stage of deterioration, at any value of oxygen content. It is seen that for all curves the variation of power factor between one millimeter and 5 centimeters pressure is scarcely noticeable. Beyond 5 centimeters the increase with pressure is at first rapid, but then becomes slower again as the very high oxygen content of 76 centimeters is approached.

Figure 18 shows the power factor-temperature relation for each pressure. At low temperatures (20 degrees centigrade) the power factor is less than 0.004 for all values of oxygen content, and at 76 centimeters is only 1.8 times that at 1 millimeter. The differences are increasingly great, however, at higher temperatures. Thus the well-known influence of increased temperature in increasing the rate of oxidation is reflected in these power factor curves. In the 2 lower curves the practically linear increase may be explained as due to decreasing viscosity and increased ionic mobility. But the rapid rise in the 2 upper curves seems to require other explanation inherent in the oxidation process, such as the liberation of gas (hydrogen) and the consequent formation of water, and the formation of organic acids. Or more simply, we may note that the "velocity constant"[26] of the oxidation reaction increases exponentially with the temperature. If the reaction itself provides (even temporarily) an increase in the number of free ions, the observed increase in power factor is readily accounted for. Further evidence in support of this view is given later. No visual evidence of gas was found in the dismantling of any of the specimens. Figure 17 shows the temperature increase of power factor as function of the oxygen impregnating pressure.

Figure 16 shows the rapid increase beyond impregnating pressure 5 centimeters of ionization factor with value of oxygen content. The increase is very slight at one millimeter and at 5 centimeters, but very pronounced at higher impregnating pressure, as may be also seen in the power factor-voltage curves of figure 20 for 10 centimeters, and figure 21 for 76 centimeters. These increases of power factor with electric stress are not due to the liberation of gas, and to gaseous ionization; no free gas or other traces of ionization of this character were encountered. Rather the increase is to be attributed either to an increase in the number of ions due to some type of secondary ionization, or to an increase of ionic mobilities due to the stripping, under increased stress, of the outer envelopes of neutral molecules from the ions already present, or to both these causes. The flattening out of some of the power factor curves seems to support the latter view. Support of the former is found in the abrupt drop in power factor when the oxygen content and volatile products are withdrawn, as reported below; this indicates that during the oxidation process a large number of highly mobile ions are present.

Figure 19 affords a view of how the layer variation of power factor varies with oxygen content. As already stated a substantial amount of oxygen is needed to show itself in this way.

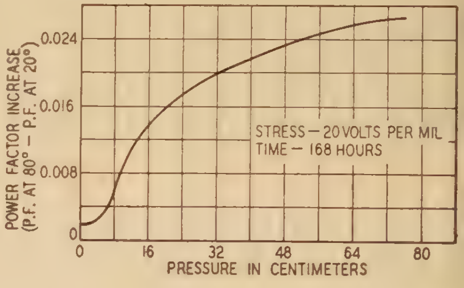


Figure 17. Temperature increase of power factor

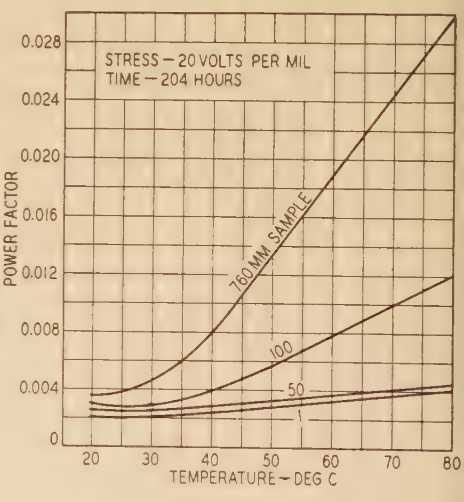


Figure 18. Power factor - temperature

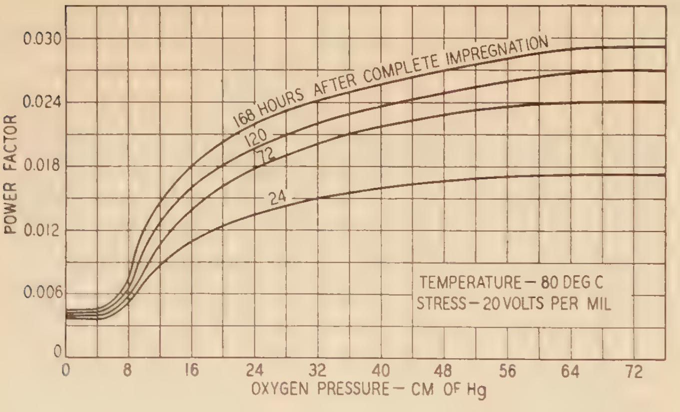


Figure 15(above). Power factor-pressure

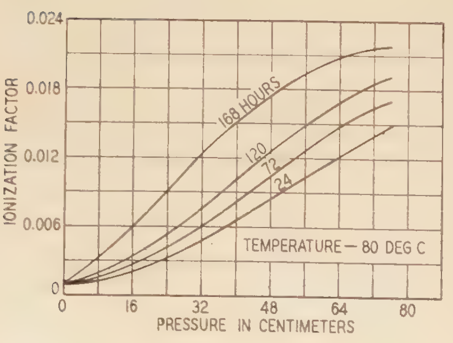


Figure 16. Ionization factor-pressure at different times after impregnation

It is interesting to note that the capacitance of all the impregnated samples over the whole range of oxygen content was the same, and remained constant over the duration of each test. This indicates that notwithstanding the heavy oxidation of the 10-centimeter and 76-centimeter samples, no appreciable molecular or ionic polarization was evident.

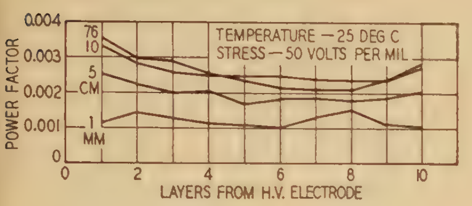


Figure 19. Layer variation of power factor

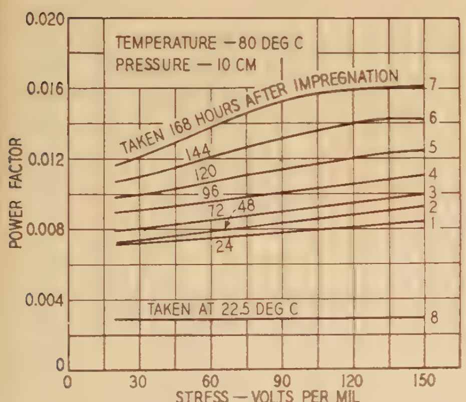


Figure 20. Power factor-voltage

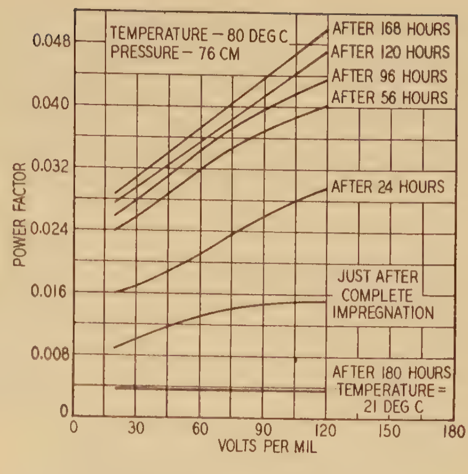


Figure 21. Power factor-voltage

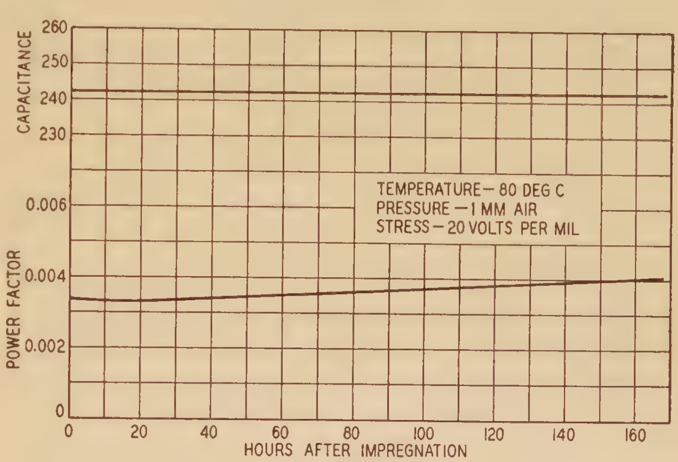


Figure 22 (below). Power factor and capacitance versus time—air

Impregnation in Air at One Millimeter Pressure. For comparison with the results using pure oxygen, a sample in which oil saturation and paper impregnation took place in *air* at one millimeter pressure, was tested, all technique being the same as for the sample impregnated at one millimeter of oxygen. The results are shown in figures 22, 23, and 24. Certain noticeable differences from the oxygen sample are evident. The capacitance, while constant over the duration of the test, has a substantially lower value, 243 versus 258 micromicroforad. The power factor-time curve for 20 volts per mil is about the same in the 2 cases. The power factor voltage curves at 80 degrees centigrade for oxygen are of uniform shape and progressively higher with time. Those for air show some irregularity, but at first become lower, and finally only become higher with time. The constant values at 20 degrees to 25 degrees after the oxidation runs are substantially the same. The power factor by layers after oxidation shows only small variations, with little evidence of increase at the electrodes. All of these facts indicate superior impregnation for the oxygen sample, probably due to its greater solubility in the oil. Penetration into the pores of paper is not as complete for the air sample and thus the capacitance is lower. For the same reason the ionization factor, and power factor-voltage curves are higher at the start, then decrease with slow improvement of oil penetration, and then increase again as the slow increase of oil conductivity due to oxidation makes itself felt. On dismantling the air sample after the oxidation test, a few tiny bubbles of gas were evident in the paper layer next to the high voltage electrode, but in no other layers, and this may account for the slight rise in power factor for layer 1 seen in figure 24. In general it may be said that the sample impregnated in oxygen is superior to that impregnated in air, in the matter of impregnation, and shows no evidence of more rapid deterioration in the accelerated oxidation tests.

Impregnation in Nitrogen at 10 Centimeters Pressure. As a check to the deductions made from the results of the one-millimeter air test, a test was made using nitrogen at 10 centimeters of mercury pressure, for oil saturation and for impregnation. Figure 25 shows the variation of capacitance and of power factor over the duration of the test. On both curves the dotted lines give the measured values, and the full lines the trend of the average values. The values shown are for a stress of 20 volts per mil, and it was found that at this low and constant value neither capacitance nor power factor showed any tendency to change. However, power factor-voltage runs at intervals, up to 150 volts per mil, always resulted in a large increase followed by decrease to steady values at 20 volts per mil. The general sequence of these changes is indicated in the dotted lines of figure 25.

The decrease of the ionization factor, figure 26, and the continuous fall of the position of the power factor voltage curve with time, figure 27, are clear evidence of delayed impregnation. Power factor values at the end of the test

are generally of the same values as found in the one-millimeter oxygen test, showing the inert property of nitrogen and the very low oxidation activity at one millimeter oxygen content. The high position of the initial power factor-voltage curve is probably due to free nitrogen and gaseous ionization; small bubbles of gas were

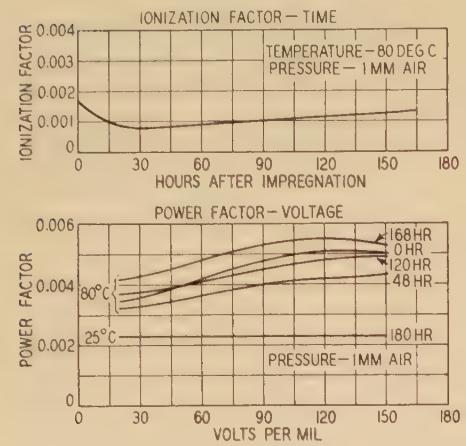


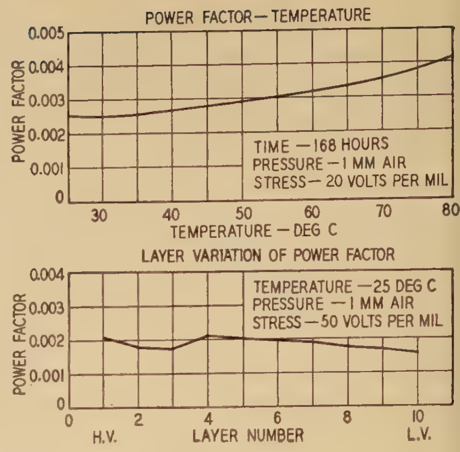
Figure 23. Power factor-voltage and ionization factor-time

found in the paper layers next to the electrodes but not elsewhere. Increasing the gaseous ionization by increase of voltage, seemed to stimulate the impregnation process, figure 25. The gas at the electrodes apparently also accounts for a slightly increased power factor (0.0032) of the paper layers next the electrodes, as compared with the approximately constant value (0.0028) of the interior layers.

It will be noted that the behavior of the one-millimeter air specimen presents several of the features of this specimen heavily saturated with nitrogen; for example, initial decrease in ionization factor, initial fall of position of successive power factor-voltage curves. There is a distinct indication that the nitrogen is playing its part in the one-millimeter air specimen.

Properties of Oxidized Oil. After each test the oil was drawn off the specimen and electrical measurements made on it. Thus there were available a series of oils oxidized for approximately 200 hours at 80 degrees centigrade in the presence of brass and paper, but at different constant amounts of contained free oxygen indicated by 0.013, 0.70, 1.40, and 10.4 per cent, respectively, of the constant volume of oil. The power factor-temperature curves of figure 28 and the power factor-voltage curves at 80 degrees, figure 29, show the relatively small difference in power factor over the range, pure oil—one millimeter—5 centimeter oxygen content, the rapid increase above 5 centimeters and the slower rate of rise toward 76 centimeters. The power factor-voltage curves of these deteriorated oils at 20 degrees centigrade were all found to be perfectly flat up to 60 volts per mil, but at 80 degrees centigrade all show the rising characteristics of figure 29, that is, some form of internal liquid ionization which increases with stress. The explanation is not obvious; possibilities in the order of their probability would appear to be increased ionic mobility, increase in free ions liberated during the process of oxidation, and increased ionization by collision with increasing stress. The concurrent dominating influence of temperature is shown by the flat power factor-voltage curves at 20 degrees for all samples. The electrical characteristics of the deteriorated paper samples follow the same general trends as those of the oil withdrawn from them, indicating clearly the influence of the oil on the characteristics of impregnated paper.

Figure 24. Power factor - temperature and layer variation of power factor



Influence of Brass and of Paper on Oil. It has been assumed in the foregoing that the small increases in power factor found in the tests of the sample having one millimeter oxygen content were due to oil oxidation. However, during these tests the oil is in contact with both brass and paper and it remains to be seen whether or not these elements have any effect on the pure oxygen-free oil. In order to obtain a quantitative answer to this question, 3 identical pure samples of oil were prepared and heated for 48 hours at 80 degrees centigrade under the following conditions: (1) oil alone; vacuum 0.1 millimeter; (2) oil plus 800 square inches of paper; vacuum 0.1 millimeter; (3) oil plus 40 square inches of clean sheet brass; vacuum 0.1 millimeter. The heating took place in a Pyrex glass flask and before the oil was admitted paper and brass were given thorough degassing and dehy-

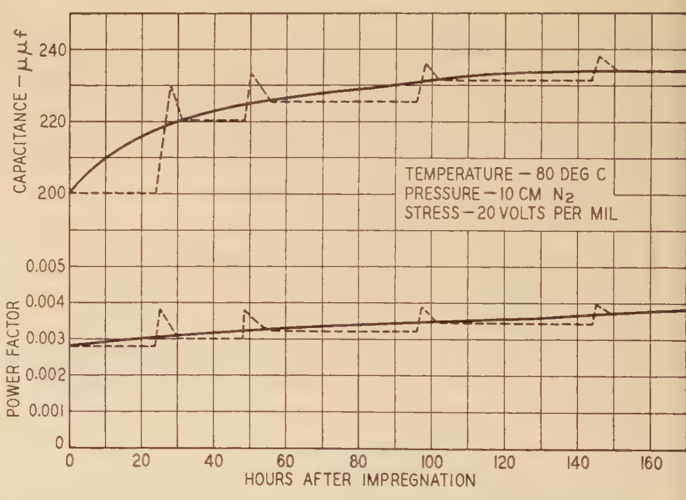


Figure 25. Power factor and capacitance-time

drating treatments at 105 degrees centigrade and 0.1 millimeter vacuum. At the end of each test the sample was cooled to room temperature, then placed in the test cell and a power factor-temperature run made. The results of the 3 tests are given in figure 30 (which also shows results of a similar test on the oil drawn from the 10-centimeter nitrogen sample after the deterioration test).

We note from figure 30 that in these 3 identical tests, contact with paper and contact with brass have each caused an increase in power factor over the values found for oil alone, and that these increases are greater with increasing temperature. These increases are thus not due to oxygen in the oil, and if due to oxygen at all it can only be that absorbed in the metal and on the surfaces of the paper fibers. The values of power factor at four

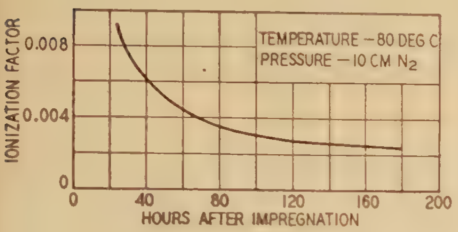


Figure 26. Ionization factor-time

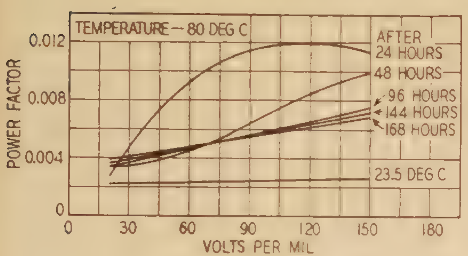


Figure 27. Power factor-voltage

temperatures are given in table IV. The fourth line, "brass and paper" is gotten by adding to the values for pure oil the *increases* in power factor caused by paper and by brass separately. As seen the values obtained by this simple approximate method of computing the joint total effect, agree closely with the measured values on the

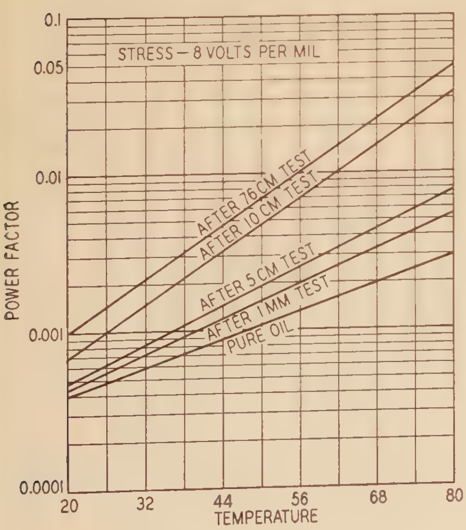


Figure 28. Power factor-voltage

one-millimeter oxygen sample. In other words, in the latter sample contact with paper and brass alone are sufficient to account for the observed values; the small amount of oxygen present in the one-millimeter oxygen sample, in spite of the high temperature, 80 degrees centigrade, appears to play no part in the observed increases in power factor.

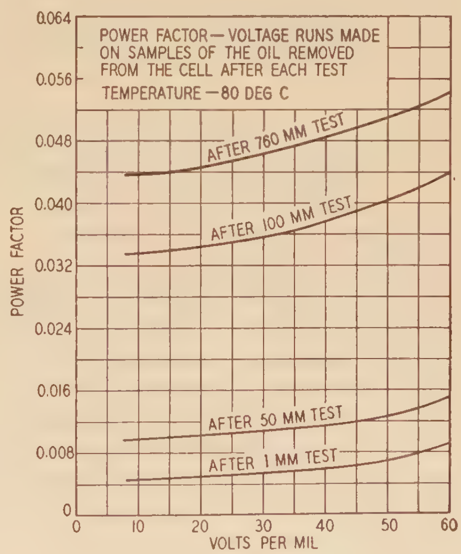
Ionization in the Process of Oxidation. Oxidation is very slow at 25 degrees centigrade; power factor voltage curves

Table IV. Power Factor

	20 Deg. C.	40 Deg. C.	60 Deg. C.	80 Deg. C.
Pure oil	0.00040	0.00076	0.00150	0.00300
Plus paper	0.00040	0.00086	0.00180	0.00390
Plus brass	0.00044	0.00095	0.00220	0.00480
Brass plus paper	0.00044	0.00105	0.00250	0.00570
One-millimeter sample	0.00044	0.00100	0.00240	0.00545

at this temperature for the whole range of oxygen saturation are flat and power factor values for oxygen saturation at 76-centimeter pressure are only about twice those at one millimeter. On the other hand, these differences are greatly increased as the temperature rises, as seen in figure 18. At low saturation (one millimeter and 5 centimeters) the power factor increases linearly with temperature, indicating increasing conductivity, and possibly a linear oxidation increase. However, for higher oxygen contents something else is going on as indicated by the more rapid

Figure 29. Power factor - temperature



rise of power factor with temperature. At 80 degrees the power factor of the 76-centimeter sample is now eight times that of the one-millimeter sample. These variations strongly suggest that the *process* of oxidation itself, as well as the oxidation products, contribute to the measured value of power factor. In order to test this question a sample of oil was thoroughly purified and degassed; then saturated with oxygen at 76 centimeters pressure, and maintained at this pressure and at 80 degrees

centigrade for 65 hours in a glass vessel. It was then admitted to the test cell under the same conditions, and the power factor measured at intervals over a further 72 hours. The sample was then evacuated down to 0.2 millimeter of mercury pressure, thus drawing off the oxygen and volatile oxidation products. Power factor observations were continued over a further 55 hours.

The results are shown in figure 31. Initially, the pure oil had a power factor 0.003 at 80 degrees; saturated with oxygen at 76 centimeters pressure, after 65 hours at 80 degrees centigrade in a glass vessel, the value rises to 0.01. At this value it was introduced into the power factor test cell. As seen from the curve a very much more rapid increase of power factor sets in. This is due to the catalytic action of the brass electrodes. The initial rate of rise is not maintained, however, and the power factor-time curve seems to be approaching a constant value. At 72 hours oxygen and volatile products were removed; the power factor dropped rapidly and within a short time reached a steady value about 25 per cent lower.

Evidently oxidation in the oil causes 2 types of power factor increase, one a permanent change due to nonvolatile products, as indicated in the final steady value of figure 31, and the other due to ions liberated in the process of oxidation, or to an ionized condition of the volatile oxidation products. This second source of ions disappears in the absence of free oxygen. It is known that oxidation may be accelerated by electrochemical processes,[27] indicating that the ions involved in oxidation reactions are associated with the conduction current. Apparently we have something of this kind here.

Power factor-voltage curves taken before and after the oxygen is removed indicate that both elements of power factor increase with increasing stress. Apparently

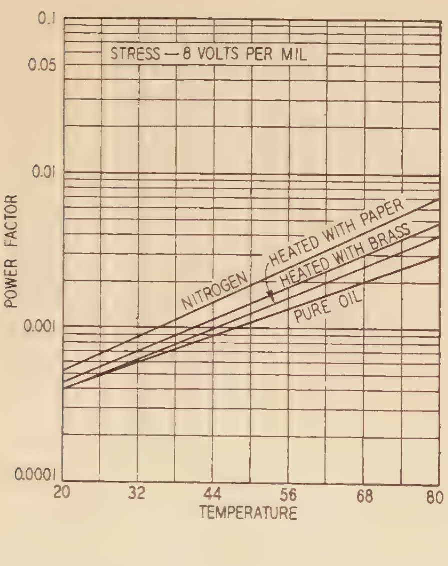


Figure 30. Power factor - temperature

the volatile active oxidation ions move faster, or cause more ionization by collision, as the stress increases. The rise of power factor due to the nonvolatile ions has been discussed in an earlier paragraph.

Catalytic Action of Brass. The catalytic action of certain metals in accelerating oxidation in oils is well known[27,28,29] though few quantitative studies have been reported. Copper and brass are among the most active metals, and consequently the problem of restricting oxidation in insulating oils is not only that of selecting oils inherently most highly stable against oxidation, but of

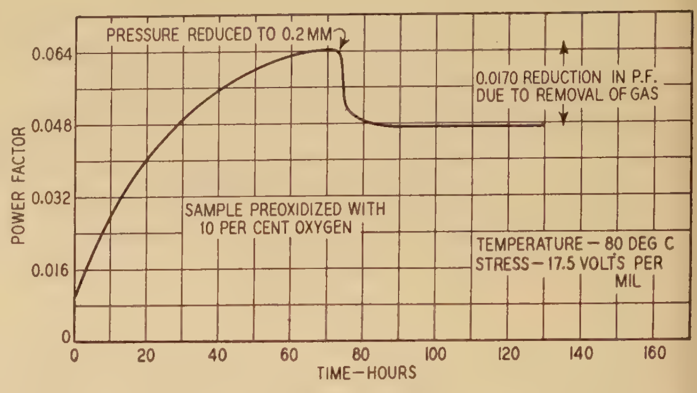


Figure 31. Power factor-time

basing this selection on the behavior in the presence of copper. For the contact of insulating oil with copper conductor, or other metal is unavoidable.

In the present work all electrical measurements have utilized brass electrodes. The resulting accelerating influence on oxidation has been evident at several points; for example, the more rapid rise of power factor-temperature curves of the samples containing more oxygen, figure 18. (Note however the apparent absence of the effect at low oxygen content.) In order to obtain evidence of the relative importance of the effect, oxygen absorption tests were run on 2 identical samples of oil, one containing 65 square centimeters of clean sheet brass. Each 1,000-cubic-centimeter sample of degassed oil was placed in a 2,000-cubic-centimeter glass suction flask exposing a surface arc of about 108 square centimeters of oil. The pressure was reduced to 0.1 millimeter, temperature raised to 80 degrees, and dry oxygen admitted at 76 centimeters of mercury pressure; the oxygen was maintained at this pressure and the amount entering each flask was measured at intervals. This amount is a measure of the oxygen entering into chemical combination. The results are shown in figure 32. The rate of absorption in both cases is at first quite rapid, and this probably represents solubility rather than oxidation. There is also some suggestion of an induction period, or delay in the final process, between 30 and 60 hours. The period beyond 150 hours probably best represents the relative rates of oxidation. As seen it appears that the oil alone is approaching a stationary or saturated condition with no further oxidation. The sample containing brass, however, is still absorbing oxygen rapidly indicating continuous auto-catalytic oxidation.

The general trend of the power factor-time curves of paper impregnated at high oxygen content, is much the same as the upper curve of figure 32. Other results, for example the higher power factors of paper layers next the electrodes, also indicate the powerful influence of the

brass electrodes, in the presence of appreciable amounts of oxygen, on the rates of oxidation, and consequent changes in electrical properties. The results throughout therefore involve not only oil oxidation, but especially oil oxidation in the presence of a metal catalyzer. This, however, is essentially the condition prevailing in practice. The separate influence of the oil alone is evident in several studies, but in view of the above facts, becomes of lesser interest for the practical problem. Further studies of autocatalytic action will be essential for complete understanding and control of oxidation deterioration in insulating oils.

Conclusions

Accelerated oxidation tests have been made on an insulating oil, with oxygen introduced over the range 0.013 to 10.4 per cent, by volume. Similar tests were made on wood pulp paper impregnated with the oils with oxygen content maintained. The outstanding conclusion

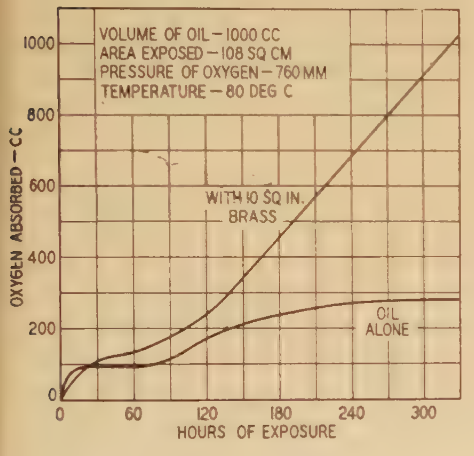


Figure 32. Oxygen absorption-time showing the catalytic effect of brass

of the work is the relative unimportance (over the duration of the tests—200 hours at 80 degrees centigrade), of small amounts of oxygen as a cause of change of electrical properties.

1. At impregnating pressures up to 5 centimeters of oxygen (0.7 per cent volume content) the electrical properties of impregnated paper show little or no instability due to oxygen content.

2. Power factor values and changes found in specimens impregnated in oxygen at one millimeter pressure, are completely accounted for by changes in the oil due to contact with paper and with metal electrodes in practically complete absence of oxygen.

3. Impregnation in oxygen at one millimeter pressure results in better characteristics than impregnation in air at the same pressure apparently due to the greater solubility of oxygen than of nitrogen.

4. A critical range of impregnation pressure is found between 5 centimeters and 10 centimeters (0.7 to 1.5 per cent volume content of oxygen). Power factor values increase rapidly with oxygen content, and also with time. Beyond 10 centimeters the rate of these changes falls off; at 76 centimeters a saturation condition represented by constant high values is indicated.

5. The *process* of oxidation in oil is a source of increased liquid or gaseous ionization, and of consequent increased dielectric loss in both oil and impregnated paper. Withdrawal of oxygen and volatile products causes large and immediate reduction of power factor.

6. Rising power factor voltage curves are found for all oil and impregnated specimens at 80 degrees. The rise is more rapid in specimens in which oxidation is in progress than those from which all gas has been withdrawn after oxidation. All such curves are flat up to 150 volts per mil at 25 degrees centigrade.

7. The change of power factor with temperature above 30 degrees centigrade is the most sensitive indicator of oxidation—better, for example, than the power factor-voltage relation.

8. Oxidation and deterioration of the oil is greatly accelerated by the catalytic action of brass. The behavior of impregnated specimens may be largely influenced by this effect.

9. Power factor tests of paper layers following oxidation runs show no increase in layers next the electrodes in the one-millimeter specimens, a very slight rise for the 5-centimeter specimens, and a definite rise above average values only for oxygen contents above 0.7 per cent by volume (5 centimeters pressure of oxygen impregnation).

10. The evidence of these tests is that the continued process of oxidation rather than the products of oxidation is the cause of oil and paper deterioration. Small amounts of oxygen either combine or go into solution without serious impairment of electrical properties.

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Discussions

Of AIEE Papers—as Recommended for Publication by Technical Committees

ON THIS and the following 13 pages appear discussions submitted for publication, and approved by the technical committees, on papers presented at the 1937 summer convention, Milwaukee, Wis., June 21–25; the Pacific Coast convention, Spokane, Wash., August 30– September 3, 1937; and the North Eastern District meeting, Buffalo, N. Y., May 5–7, 1937. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in ELECTRICAL ENGINEERING, which discussion will be reviewed by the proper committee and considered for possible publication in a subsequent issue. Discussions of papers scheduled for presentation at any AIEE meeting or convention will be closed 2 weeks after presentation. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to AIEE headquarters, 33 West 39th Street, New York, N. Y.

The Saturated Synchronous Machine

Discussion of a paper by B. L. Robertson, T. A. Rogers, and C. F. Dalziel published in the July 1937 issue, pages 858–63, and presented for oral discussion at the electrical machinery session of the Pacific Coast convention, Spokane, Wash., September 2, 1937.

R. H. Park (The Calco Chemical Company, Inc., Bound Brook, N. J.): The following analysis of saturation phenomena which was worked out by the writer a year or so ago in an effort to develop a simplified yet adequate theory of saturation effects in salient-pole synchronous machines is submitted as discussion of Messrs. Robertson, Rogers, and Dalziel's paper with the thought that they or others may care to check experimentally the theoretical developments presented.

It should be unnecessary to point out that any useful theory must represent a good compromise between precision and convenience, and with this thought in mind it is believed that we are warranted in considering the usefulness of the assumption that the field pole tips and faces of salient-pole machines may be regarded, for purposes of calculation as not being subject to saturation effects, despite the fact that we recognize the fact that in many cases pole-tip saturation effects do exist to an at least appreciable extent.

With this assumption which will be utilized in what follows, and the further rather implied assumption that there is no significant saturation in the quadrature axis, we note that whatever the field below the pole faces there will be a definite magnetic potential between adjacent pole faces and that the magnetic field in the air gap will be the same as it would be if the rotor were unsaturated and the field current had some appropriate value say I different from its actual value with saturation which we will designate as I_s.

Now as to the effects of stator saturation we may note that these may be thought of as equivalent to introduction into an unsaturated stator of suitable counter magnetomotive forces arising where the stator flux density is a maximum and producing a resultant distortion of the stator and air-gap fluxes relative to what would otherwise obtain.

We shall at this point introduce the postulate that the effect of this counter magnetomotive force may be regarded with sufficient accuracy as being equivalent to the effect of an added space fundamental component of armature current say $\mathbf{i}_{sc}$ where

$\mathbf{i}_s$ = actual (space vector of) armature current

$\mathbf{i}$ = equivalent unsaturated armature current

$= \mathbf{i}_s + \mathbf{i}_{sc}$

Thus we will have

I_{sc} = saturation component of field current

$$= I_s - I \tag{1}$$

$\mathbf{i}_{sc}$ = saturation component of armature current

$$= \mathbf{i} - \mathbf{i}_s \tag{2}$$

Evidently by virtue of our definitions of I and $\mathbf{i}$ they must specify the magnetic state of the air gap, and hence the torque, these being what would obtain with these currents and no saturation.

As a consequence of our postulates we note that I_{sc} must depend wholly on the value of flux in the pole, hence only on I and i_d, i.e., in general I = funct (I, i_d) where the function in question may be specified in terms of a series of zero-power-factor curves.

But also the fluxes emanating from the pole face and between the pole tips tend to be substantially linearly related to I and i_d while there will be a general tendency for the fluxes emanating below the pole tips to be proportional to I, and hence there will be a tendency for I_{sc} to be exclusively a function of a linear function of I and i_d, i.e., it will be approximately true that

$$I_{sc} = F(\Phi) \tag{3}$$

where

Φ = *effective per unit field flux*

$$= I - ki_d \tag{4}$$

$= \psi_d + x_{fs} i_d$

k = a constant

$x_{fs} = x_d - k$

= *field saturation reactance*

As regards the saturation component of armature current, in a stationary armature machine this may be assumed to be associated and in space phase with a flux $\bar{\phi}$ which is intermediate in size and phase between the space fundamental armature flux linkages and the air gap flux $\psi + x_l \mathbf{i}_s$ so that we may assume in general that

$$\mathbf{i}_{sc} = f(\bar{\Phi}) \tag{5}$$

where

$\bar{\phi}$ = effective per unit armature flux

$= \bar{\psi} + x_{as} \mathbf{i}_s$

$$x_{as} = \textit{armature saturation reactance} \tag{6}$$

though for most practical purposes it is possible that we could assume $x_{as} = 0$ with little error.

Evidently the character of the functions F and f may be determined by tests respectively at high field, low terminal voltage, and low field high terminal voltage and the results so obtained utilized for computing excitation under any arbitrary head conditions.

Just as we recognize that $\bar{\phi}$ is nearly equal to $\bar{\psi}$ so we may readily recognize that Φ will be nearly equal to the field linkages $\bar{\Psi} = \psi_d + x_d' i_d$, so that it would be expected that x_{fs} is approximately equal to x_d'. Actually x_{fs} must exceed the *saturated* value of x_d' at any value of Φ since if i_d is varied so as to hold Ψ constant it will be evident from a consideration of the detail flux conditions in the pole that I_{sc} will increase as I increases.

Since x_d' is known to vary considerably with saturation the suggestion is clear that x_{fs} may and in fact should be assumed, in general, to vary with saturation. That is, we may take x_{fs} = funct (Φ), a procedure which at once increases the range of validity of equations 3 and 4. Obviously x_{as} could also be treated as a function of saturation. However this would appear to be an unnecessary refinement.

Tests to determine the variation of x_{fs} with saturation are easily carried out by simply comparing the no-load and full-load saturation curves, after making allowance for stator saturation, and we see, therefore, that to the extent that stator

saturation may be ignored x_{fs} is in reality identical with Potier reactance. This demonstrates that in general Potier reactance must tend, except for the effect of stator saturation, to equal and in fact to exceed transient rather than leakage reactance a fact which seems to have frequently escaped recognition. On the other hand Potier reactance, as ordinarily defined, is not identical with x_{fs} since it does not make allowance for stator saturation, a circumstance which is believed to account in the main for the very large variations with saturation at high values of armature voltage which were reported in a recent paper by March and Crary.

To show an application of the theory developed we may note that under ordinary load conditions it does not appear that armature saturation of revolving field synchronous machines is of great influence on stability, and that in any case, if we disregard armature saturation, the steady state coefficient of synchronizing torque $T_s = dT/d\delta$

where

δ = displacement angle

and

T = per unit torque

$$= i_q\psi_d - i_d\psi_q = i_qI - (x_d - x_q)i_di_q \quad (7)$$

is

$$T_s = i_q\frac{dI}{d\delta} + \{I - (x_d - x_q)i_d\}\frac{di_q}{d\delta} - (x_d - x_q)i_q\frac{di_d}{d\delta} \quad (8)$$

But for a machine connected to an infinite bus of voltage e (external impedance included in machine constants) there is

$$(r^2 + x_dx_q)i_d = x_q(I - e\cos\delta) - r\,e\sin\delta \quad (9)$$

$$(r^2 + x_dx_q)i_q = r(I - e\cos\delta) + x_de\sin\delta$$

while since I_s is assumed constant

$$\frac{dI}{d\delta} = -\frac{dI_{sc}}{d\delta} = \left\{\frac{\partial I_{sc}}{\partial I}\frac{dI}{d\delta} + \frac{\partial I_{sc}}{\partial i_d}\frac{di_d}{d\delta}\right\} \quad (10)$$

$$= a\frac{di_d}{d\delta}$$

where

$$a = \frac{-\dfrac{\partial I_{sc}}{\partial i_d}}{1 + \dfrac{\partial I_{sc}}{\partial I}} \quad (11)$$

Then if we introduce the quantity

x_{ds} = *saturated synchronous reactance*

$= x_d - a$

we find after some transformations

$$\frac{di_d}{d\delta} = \frac{e(x)_q\sin\delta - r\cos\delta)}{r^2 + x_{ds}x_q} \quad (12)$$

$$\frac{di_q}{d\delta} = \frac{re\sin\delta - x_{ds}e\cos\delta}{r^2 + x_{ds}x_q}$$

results which in conjunction with (8) and (10) permit ready evaluation of T_s for any value of δ.

For $r = 0$, for example, we find in detail

$$T_s = \frac{Ie\cos\delta}{x_d} + \frac{x_d - x_q}{x_dx_q}e^2\cos 2\delta + \frac{x_d - x_{ds}}{x_dx_{d_s}}e^2\sin^2\delta \quad (13)$$

only the first 2 terms of which are retained in the absence of saturation.

In the special case in which x_{fs} is assumed constant we have from (3) and (4)

$$\frac{\partial I_{sc}}{\partial I} = F'(\Phi)$$

$$\frac{\partial I_{sc}}{\partial i_d} = -(x_d - x_{fs})F'(\Phi)$$

$$a = \frac{(x_d - x_{fs})F'(\Phi)}{1 + F'(\Phi)}$$

which as saturation is sufficiently increased approaches in the limit $a = x_d - x_{fs}$, corresponding to $x_{ds} = x_{fs}$.

Surge Protection of Distribution Systems

Discussion and authors' closure of a paper by J. K. Hodnette and L. R. Ludwig published in the June 1937 issue, pages 683–8, and presented for oral discussion at the lightning protective equipment session of the summer convention, Milwaukee, Wis., June 24, 1937.

Herman Halperin (Commonwealth Edison Company, Chicago, Ill.): I presume that the upper of the 2 curves marked C in figure 2 is for deion gaps and the other curve is for arrester gaps. Do the characteristics in figure 2 hold substantially for all voltage ratings?

Over 90 per cent of our 4,000-volt overhead distribution system has solid interconnections between the neutral of the 3-kv arrester and the secondary neutral, which is grounded to water pipes on the customers' premises. As a safety measure, the transformer case is not grounded. Our experience is that about one-quarter of one per cent of the transformers fail annually due to lightning even with this interconnection. Most of these are in older transformers, but occasionally a modern one fails. This experience tends to create some doubt in our minds as to the possibility of obtaining a comparatively high degree of protection if protector tubes with initial discharge voltages of 9 times normal voltage were used in place of the arresters that discharge at much less than half those values, except as applied to specially designed transformers.

Referring to the authors' expectation that the maximum surge currents on distribution lines "would be of the same order as those obtained on high-voltage transmission lines," this is not confirmed by measurements of arrester discharge currents, using surge crest ammeters. We have installed surge-crest-ammeter links in the ground lead of 3-kv arresters at about 320 scattered locations over the city of Chicago. During the years 1934–36 the links indicated sizable arrester discharge currents in 121 cases. In most cases the currents were less than 1,000 amperes, in 44 cases the currents were between 1,000 and 5,000 amperes, and in 6 cases the currents were from 5,000 up to 9,000 amperes, the maximum value.

Referring to the third paragraph of page 685, a few recent measurements in Chicago have indicated roughly the same order of surge current through adjacent phase and neutral arresters, indicating that the lightning discharge current divides rather evenly through several arresters that may be installed at one location on a 3-phase overhead line or circuit.

The arrester manufacturers have found from laboratory tests that modern distribution arresters can withstand surge currents greatly above 5,000 amperes, and this is substantiated by operating experience. It is gratifying, however, to learn of the authors' development of a device that can withstand successfully surge currents of the order of 50,000 amperes.

W. H. Cooney (General Electric Company, Pittsfield, Mass): The authors have outlined in a very comprehensive manner the surge voltages and currents which may be expected on distribution circuits and their views as to the requirements which protective devices must meet in order to provide a good quality of service.

The time-voltage curves shown in figure 2 are very interesting. Although it is not definitely stated, it appears that curve A on the "breakdown characteristics of distribution transformer insulation" is on a "single shot" basis, since curve B shows the probable voltage levels at which deterioration of insulation begins with repeated impulses. At one microsecond curve A shows a breakdown strength about 27 per cent higher than at 2.5 microseconds, a greater increase of strength with decrease of time than that shown by Messrs. Bellaschi and Teague,[1] but of about the same order as that shown by V. M. Montsinger[2] in his discussion of the Bellaschi and Teague paper.

The probable voltage level at which deterioration begins is shown by the authors as curve B, which is 90 per cent of curve A for time greater than 2 microseconds. This may be compared with Montsinger's discussion[2] which showed a corresponding representative value of 80 per cent, with a variation from 70 to 90 per cent depending on the kinds of electrodes used in the tests. It should be noted that the authors' curve B at one microsecond has dropped to 83 per cent of curve A.

Considering all data at present available, it appears that a deterioration level of 90 per cent is somewhat optimistic and that the probable value lies nearer 80 per cent.

The authors refer again to a ratio of impulse crest to 60-cycle crest breakdown of 2.2. Montsinger[2] has shown that such a ratio may range between 1.75 to 2.2 (depending on the type of electrodes) for repeated impulses, a variation sufficient to indicate that the ratio is a band rather than a definite value. In addition, now that data have been presented showing an increase of transformer insulation impulse

strength below 2 microseconds, a so-called impulse ratio has even less significance.

It would appear from figure 3 and from Mr. H. M. Towne's comparison of previously published Deion gap data with the data in figure 2 and table 1, that the authors consider satisfactory a very small margin between the performance of the protective device and the demonstrated strength of the transformer. While protection can be demonstrated by an AIEE impulse test with a new transformer it is doubtful whether this initial margin will be adequate for the deterioration due to repeated impulses and other conditions of service. The authors show that at one microsecond (figure 2) the deterioration level is 83 per cent of the impulse breakdown strength.

While a properly maintained and protected transformer should retain its initial impulse strength indefinitely in service, past experience has indicated that deterioration may occur on some percentage of distribution transformers in service. Some operating companies have recognized this fact by applying to transformers taken out of service only about 65 to 75 per cent of the original factory high-potential test.

It is not generally considered economically feasible to give distribution transformers the degree of maintenance and inspection given to substation and power transformers. As a result, some portion of the transformers in service may have low oil levels, thus exposing parts which are dependent on oil for full insulation; water may enter even into sealed transformers due to failure to close covers tightly after opening for inspection, tap change, etc.; and excessive overloads may be carried to the point of carbonization of insulation. Any of these factors tend to lower the impulse strength of the transformer.

In order to avoid trading on the margin of strength above the demonstrated value it would seem essential to provide a wide margin between the demonstrated impulse strength of the transformer and the voltage levels permitted by the protective device, in view of the effect of repeated impulse voltage and the possibility of deterioration of impulse strength in service.

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L. G. Smith (Consolidated Gas, Electric Light, and Power Company of Baltimore, Baltimore, Md.): In reference to section 4 on normal frequeny requirements of lightning protectors, it is believed that the lightning arrester designer should give the operator applying lightning arresters accurate data based upon numerous tests of the actual cut-off of the arrester. While it is the practice of the manufacturers to rate arresters in terms of maximum 60-cycle voltage which can be applied to the arrester, this voltage rating is below the actual maximum cut-off voltage of the arrester by some margin of safety. Unfortunately the margin of safety assumed by the various designers is extremely variable. It is believed that this margin has gradually been reduced in recent years by most arrester manufacturers. For this reason it is quite important that operating engineers applying arresters have definite test data showing the actual maximum cut-off voltage of the arrester.

As an example of the need for this information, the operating company may have used arresters of a certain rating on their system for a number of years with satisfactory results and it may be that the particular arrester on which the operating results were obtained had a considerable margin between its rated voltage and the maximum cut-off voltage, which margin may have contributed to the satisfactory operation of the arrester. Based upon this operating experience arresters of another type having a reduced margin of safety may be installed and arrester failures result, due to inability of the arrester to cut-off. In view of the fact that the characteristics and possible overvoltages vary with different systems and are not consistent for various lines on a given system, it is quite essential that the operating engineers have complete information on arrester characteristics so that they can apply arresters intelligently.

H. M. Towne (General Electric Company, Pittsfield, Mass.): The authors have presented a very interesting paper on a vitally important subject. The adequate protection of distribution systems from lightning has been given quite thorough study over the past 10 years, and practical operating benefits from these studies have been pyramiding over several years.

The problem of protection of distribution transformers involves many important aspects. First, the protective scheme must be simple and economical. Second, the degree of protection should be liberal—allowing ample margin between the discharge level of the protective device and the impulse strength of the transformer insulation after years of service involving the usual influences of excessive overloads such as possible carbonization and release of water; poor oil, or other weakening of insulations; moisture; any of which may occur on a percentage of transformers in service. Third, this liberal margin of protection should be realized as far as possible under the rare cases of steep wave and high-current lightning discharges, without sacrificing too greatly in the protection level or other factors of security for the greatly predominant, year in and year out, nominal discharge duty. Fourth, the overvoltage protection should not interfere with conventional and recognized good practices in primary fusing and overcurrent protection. Fifth, the lightning protective device should function so as to minimize any hazard of primary power voltage and current on the secondary or consumer's circuit—i.e., afford the greatest possible preservation and protection to that transformer insulation which separates the low voltage consumer circuit from the dangerous high voltage primary circuit—and minimize the primary power voltage or current reaching the secondary circuit attending the discharge of the primary lightning protective device.

Considerable has been written about the desired level of protection to allow for various factors not always present in limited laboratory demonstrations. In the August 1929 *Electric Journal*, A. L. Atherton stated:

"The criterion should be not merely that a complete failure is not brought about by a single application of surge voltage, but that no damage is done." "Tests have been made . . . using surge voltages covering a wide range of both magnitude and duration, using a variety of insulating materials and making literally millions of observations as a means of securing both limiting and average values to cover the variations which are inevitable in small insulation samples. The indications are that the damage to insulation begins at possibly 2.5 times the value which would be used at line voltage, taking into account the factors of safety normally used in apparatus design for 60-cycle strength. Service experience where there has been opportunity to observe the lightning damage for several years unprotected and then protected has shown that about 90 per cent of the lightning damage is removed by this arrester (3-kv maximum arrester for 2,400-volt circuits) having 3.5 ratio. The modified auto-valve arrester (also for 2,400-volt circuit protection) with a ratio of 2.5 instead of 3.5 . . . has been observed . . . after a few thousand arrester years service no case of apparatus damage has been recorded. . . . Service records have been made with average transformer installations, including both old and new; and with various relations between transformer rating and line insulation."

In the AIEE paper "Development of the New Auto-valve Arrester" presented in January 1930, the authors, Dr. Slepian, Tanberg, and Krause state:

"Extended tests in the laboratory on insulation protected with arresters have indicated that there is probably no deterioration of insulation with arresters having ratios not exceeding 2.5."

In discussing lightning arresters in the February 1930 *Electric Journal*, Edward Beck states:

"A good lightning arrester should have a ratio of not more than 4 to 1." . . . "In the new autovalve arrester, ratios of 2.5 and less are secured. . . ."

Again, in the May 1930 *Electric Journal*, Dr. Fortescue discusses the general problem of protection and states:

"Years of experience with . . . protective ratio between 3 and 3.5 have proved that approximately 90 per cent of the lightning troubles . . . are removed. . . . Several thousand arrester years of field experience with arresters employing a protective ratio of 2.5 has not brought to light any failures of apparatus thus protected. This experience very strongly substantiates the conclusion . . . that the protective ratio of 2.5 is the ideal. . . . It is generally

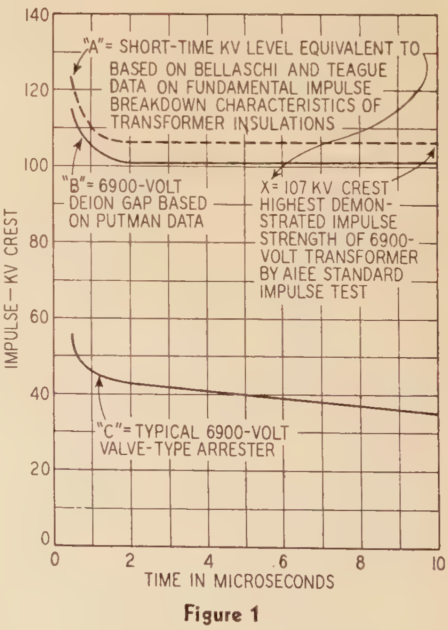


Figure 1

accepted that fibrous insulation—which constitutes a large part of the insulation of the transformer—will in course of time deteriorate when subjected to surges above 2.5 times the rating repeatedly. If the surges do not rise above this value, the life of the transformer is indefinitely long."

In view of what was apparently a very extensive study of the fundamental behavior of apparatus insulations in general, in both laboratory and field, as evidenced by these fairly recent articles advocating not more than 2.5 to 1 ratio, it is somewhat difficult to reconcile the present statement by Messrs. Hodnette and Ludwig that "a high degree of protection is obtained with a ratio of protective device discharge to normal frequency voltage of 9 to 1." To avoid trading on the factor of safety above the AIEE demonstrated test strength and also to allow for insulation deterioration which may occur over years of service due to the causes previously cited, it would seem that a much better degree of protection than 9 to 1 is highly desirable.

The authors' curves, figure 2, do not permit a clear understanding of the co-ordination and margin of protection. As pointed out by the authors, knowledge of the insulation strength of transformers to impulse voltages is necessary to intelligently co-ordinate and successfully apply protective devices. Since the curves are all to a percentage ordinate, it is difficult to gain the relationships on a kilovolt basis, utilizing the known demonstrated strength of the transformer insulations. One approach to the co-ordination picture is to start out with the demonstrated impulse test voltage, which is all the purchaser of a transformer knows about its lightning strength. As shown in the authors' table I, a purchaser knows that a 6,900-volt distribution transformer will withstand the 107-kv crest maximum test voltage of the AIEE standard impulse test for the $1^1/_2 \times 40$ full-wave condition. From this 107-kv full-wave test plotted at 6 or 10 microseconds, a curve for the short-time kilovolt strength of the transformer can be plotted using recently published data on the fundamental impulse characteristics of combined solid and liquid transformer insulations.

Messrs. Bellaschi and Teague have discussed the short-time impulse breakdown strength of transformer insulations in their AIEE paper "Dielectric Strength of Transformer Insulation" published in the January 1937 Electrical Engineering. Their comprehensive investigation shows that the impulse breakdown strength of combined solid and liquid transformer insulation is but little, if any, higher for one-half microsecond to breakdown than at the full $1^1/_2 \times 40$ wave. They show average of tests to breakdowns on test samples, of 300 kv at 0.35 microsecond; 300 kv at 2.5 microseconds; and 280 kv at full 40 microseconds, and they state "these tests for a large number of repeated impulses confirm the constant strength over the impulse region even down to the very short times as previously established." Their curves, figures 6 (for insulation breaking down at around 140-kv crest), and 7 (for insulation breaking down at around 220-kv crest), show that the impulse breakdown is flat from 10,000 microseconds down to about 1 or 2 microseconds and then turns up slightly with the breakdown at 0.5 microsecond being only 12 to 16 per cent higher kilovolt value than for the full $1^1/_2 \times 40$ wave strength. Applying these fundamental data by Bellaschi and Teague to the known 107-kv test, the accompanying curve A, figure 1 is obtained, and such a curve should represent the lightning strength for all waves and equivalent to the 107 kv highest demonstrated test on AIEE full $1^1/_2 \times 40$ wave. Whatever margin of safety exists between the 107-kv full-wave test and actual breakdown could logically be expected to exist for the short time equivalent portion of the curve. Such a procedure results in an impulse level below which lightning stresses should be limited to avoid encroaching or trading on the factor of safety above the known demonstrated strength of the transformer.

While Messrs. Hodnette and Ludwig do not give an actual impulse volt-time breakdown curve for the deion protector, such curves were given by Mr. Putman in the February 1937 *Electric Journal*. By adding Mr. Putman's data for the discharge level of the 6,900-volt deion protector as curve B to the accompanying figure 1, it appears that the margin of protection to the insulation of a new 6,900-volt transformer is relatively small—unless the factor of safety in transformer insulation above its required AIEE demonstrated strength is quite wholly depended upon.

The authors show in their figure 2 that insulation deterioration from repeated impulses alone begins at about 90 per cent of the $1^1/_2 \times 40$ full wave strength, and they state that this factor is applicable to the figures in table I. Since table I highest test level of a 6,900-volt transformer is 107 kv, the limit above which repeated impulse stresses might cause deterioration is 90 per cent of 107 or 96 kv. It would, therefore, appear that the 102-kv discharge level (Putman's data) of the 6,900-volt deion gap would result in deteriorating stresses.

In discussing the deion gap the authors state that a series resistor, is used to limit the magnitude of the large power follow current, but no data are given regarding the ohmic value. Apparently the protection level of the device involves first the impulse breakdown voltage of the gap (Curve B of the accompanying figure 1) and then an IR voltage drop due to the discharge current through the series resistor. In evaluating the impulse protection level it is of course necessary to consider this IR drop which will exist as long as discharge current flows, which may be many microseconds. For instance, if the series resistance is 5 ohms, an IR drop of 100 kv will occur with a 20,000-ampere discharge current. A one ohm resistor would allow an IR drop of 50 kv at 50,000-ampere discharge current. On the other hand a one ohm resistor would seemingly be far too low to cause any appreciable reduction in the large power-follow current. Assuming a location of the transformer at a point on the feeder or branch circuit having a line to ground short-circuit current of 1,500 amperes root-mean-square, the line impedance would be 6,900/1,500, or 4.5 ohms, and a one-ohm resistor would only reduce the line to ground short-circuit power follow current through the deion gap from the 1,500 to 1,240 amperes root-mean-square. Similarly, if the transformer were located closer to the substation where a 3,000-ampere short-circuit current is available, a one-ohm resistor would only reduce the short-circuit power-follow current from 3,000 amperes down to 2,100 amperes root-mean-square. Any 6,900-volt sectionalizing fuse link up to 40-ampere rating will be melted in $^1/_2$ cycle at approximately 800 amperes root-mean-square. Then, assuming as low as 1,500 amperes available line short-circuit current, it would appear that the series resistor would have to be at least 4.5 ohms to avoid blowing a 40-ampere sectionalizing fuse or 18.5 ohms to avoid blowing a 15-ampere sectionalizing fuse. The authors may be willing to state the ohmic value of the series resistor and clarify its effects.

The curve C of figure 1 shows the discharge level and margin of protection which may be had with a typical 6,900-volt valve-type arrester applied with interconnection.

Such a margin of protection avoids dependence on the undemonstrated factor of safety and also allows for the possible service conditions and abuses which over years of operation may depreciate the transformer-insulation below its demonstrable strength by AIEE test when new.

The authors have cited considerable information on discharge current requirements of protective devices. Probably the most significant data on the required discharge capabilities of distribution system protective devices is the direct measurement of actual lightning current magnitude through individual distribution arresters on distribution systems of various voltage classes, by Mr. H. W. Collins, and also Mr. McEachron and Mr. McMorris. Out of 500 measurements, Collins found 20,000 amperes to be the highest discharge current. McEachron and McMorris data over more than 2 years, involving about 2,800 arrester-years of observation and about 1,000 measured discharges, shows only 2 discharges of 50,000 amperes, or 0.2 per cent. This means one 50,000 ampere discharge out of 1,400 arrester years, and a probability of a single arrester receiving 50,000 amperes discharge once in 1,400 years. 99.8 per cent of the measurements were below 22,000 amperes, and about 97 per cent were under 10,000 amperes. These data show that arresters with discharge capabilities of even 25,000 amperes will give highly satisfactory service performance, and that the authors' contention that 50,000 amperes discharge capacity will give satisfactory results is quite conservative. It is particularly significant that the highest measured discharge current has been proved to be well within the capabilities of available valve-type arresters such as the Pellet type; that is, modern arresters are withstanding the current magnitudes, current durations, the steep wave fronts, the multiple or repetitive stroke, the switching surges, etc., and giving protection to very old as well as new transformers.

While some types of earlier arresters gave some troubles from moisture, corrosion, etc., the modern arresters over the past 4 or 5 years are demonstrating an extremely low mortality rate from all causes.

The valve-type arresters, of course, discharge the short time lightning currents and at the same time prevent any dangerous primary power follow current from reaching the transformer tank and low voltage secondary service.

The authors' paper is a definite contri-

bution to the subject of transformer protection. It is obviously desirable that continued and concerted efforts be directed by the large manufacturers, as well as utilities, toward attaining a complete understanding of lightning protection requirements for virtually complete protection of distribution systems.

C. S. Sprague (Purdue University, Lafayette, Ind.): The authors have presented an interesting summary of the range of lightning exposures and of the characteristics of transformer insulation and of protective equipment under 60-cycle and impulse stresses.

Curve *D* of figure 2 brings out the inadequacy of the rod gap in protecting transformer insulation in the range from 6,800 to 13,800 volts. Apparently at still higher voltages the gap would be almost worthless for short-time impulses unless set at a considerably reduced spacing.

In figure 3 the comparison between Deion gaps and valve-type arresters does not seem to be applicable unless interconnection is used with the valve-type arresters. If interconnection is not used the effect of lead and ground impedance would be to materially raise the upper limits of the band between the 2 curves *D*. Although the lightning arrester with interconnection, provides a considerably lower impulse voltage than the deion gap, it should be kept in mind that the duration of the wave is considerably longer with the valve-type arrester.

At first glance it seems from figure 3, that the valve-type lightning arrester may provide relatively greater protection, in spite of the authors' closing statement that both types provide adequate protection as demonstrated by field records. This is particularly noticeable in the 11,500 volt and the 13,800 volt range where the deion gap impulse break-down voltage (curve *E*) is quite close to the minimum impulse strength (curve *C*). By reference to curves *A* and *B* of the authors' figure 2, it would appear that the voltage permitted by the deion gap is dangerously close to the value which will produce deterioration of the insulation. Perhaps the short duration of the voltage will account for the adequacy of protection claimed for the deion gap.

J. K. Hodnette and L. R. Ludwig: Complete protection of distribution system and the apparatus connected to them is the aim and object of distribution engineers. The manufacturer contributes to this program by continually improving distribution transformers and protective equipment, and by the accumulation of data on surge protection. It was the object of this paper to present data to enable a more intelligent use and application of distribution equipment toward this end. Data has been presented on transformer insulation and lightning arrester requirements so that operating engineers could get a broader picture of this important problem.

It has been pointed out in the paper that it is necessary to provide protection under the worst conditions which result from direct, or near direct, strokes of lightning rather than the average condition. In the past, much of the data on protective devices and distribution system protection have been obtained by field trials in the large metropolitan distribution systems. With the rapid expansion of distribution systems in rural areas these data are proving inadequate. As was pointed out by Mr. F. E. Andrews, currents much in excess of those formerly expected appear on distribution systems relatively often as evidenced by damage to cutouts, insulators, and other equipment. In most cases evidence of direct strokes on distribution systems is centered about apparatus damage. This emphasizes the fact that it is the conditions of direct strokes, or near direct strokes, to the line rather than induced surges which result in the major damage to distribution systems. It is imperative, therefore, that the protective equipment be designed for the worst conditions. Field experience has indicated that it is necessary to have a discharge capacity of 100,000 amperes to prevent damage from lightning.

Figure 2 of the paper presents data on the impulse characteristics of distribution transformer insulation as compared to characteristics of protective devices. In view of the large amount of discussion on this subject further explanation of this figure is given. The data, from which curve *A* representing the breakdown characteristics of distribution transformer insulation was drawn, were determined by tests on actual distribution transformers and supplemented by tests with models. In comparing this curve with previously prepared data, it should be noted that the time lag is plotted from the start of the voltage wave instead of the time lag above the 60-cycle breakdown value which has been the conventional method in the past. This curve was derived by applying impulse voltages and increasing them in steps until the transformer insulation failed. In this respect it is not a one-shot breakdown curve. Curve *B* was determined by applying impulse voltages slightly under the minimum strength and observing the effects. It is quite difficult to accurately establish values at short time lags due to the fact that the testing technique for testing short waves has not been completely developed. Also the variation in individual samples may be misleading. Much data is necessary in order to completely establish a curve of this nature. Points that were determined were established by applying short steep-front waves to distribution transformers and chopping them by a gap flashover. Repetition of this process established points below which the insulation would not fail.

With reference to the ratio between the impulse breakdown voltage, and the 60-cycle breakdown voltage, the ratio of 2.2 applies to a well balanced insulation structure. This value is generally applied to the ratio between the 60-cycle breakdown strength and the minimum impulse breakdown strength. This ratio does not hold for all insulation structures but depends upon the type of insulation and the electrodes used. Values considerably lower and higher than 2.2 have been found on special insulation structures. The data in the paper, however, applies to distribution transformers.

Insulation deterioration under impulse voltages appears to be associated with the formation of corona. Where the design is such as to eliminate or minimize the formation of corona, deterioration does not occur, or the voltage at which it does occur approximately coincides with the breakdown voltage. Corona under oil occurs at relatively high voltage stresses. The minimum voltage required to produce corona is in general in excess of the operating and test voltages applied to distribution transformers as covered in the paper. For this reason deterioration of the insulation of distribution transformers by impulse voltages takes place very near the ultimate breakdown level. In this connection the tests made by Messrs. Bellaschi and Teague, referred to by Messrs. Towne and Cooney, were made on insulation structures for power transformers and under conditions which would permit the formation of corona. In this respect distribution transformers are in a class by themselves, and the laws applying to the insulation of high-voltage power transformers do not necessarily apply to distribution transformers, due to the discontinuous nature of insulation curves at short spacings.

There is a decided difference in opinion among engineers regarding the deterioration of insulation of distribution transformers in service. Mr. Cooney states that a properly maintained and protected transformer should retain its initial impulse strength indefinitely in service. We agree with this statement. Past experience, however, has indicated that the mortality rate of old transformers is higher than those that have been in service a few years. This has been due largely to the deterioration of bushings and cables. Previously it was common practice to depend upon the cable insulation to a large extent in insulating the primary leads from the transformer case. Exposure to weather reduced this insulation so that failure of the bushings resulted at a much lower value. The coils, however, being submerged in transformer oil and protected from moisture and oxygen deteriorated very little. Also, these transformers were so designed and protected that no protection was afforded the secondary windings against overvoltage surges. Modern transformers are built with bushings of adequate size so that it is not necessary to depend upon the cable lead insulation, and balanced protection now prevents damage to the high-voltage as well as the low-voltage windings.

Moisture in oil has often been referred to as the cause of deterioration of distribution transformer insulation. A large percentage of the distribution transformers in service at the present time are operating with water in the bottom of the transformer cases. Modern distribution transformers are made tight which prevents the entrance of water and helps to protect the oil from excessive oxidation.

Excessive overloads have been referred to as the cause of insulation deterioration and ultimate failure. The deterioration strength of transformer insulation does not materially decrease until the temperature is reached which produces a chemical change in the insulation. This is usually evidenced by formation of gases. Sustained temperatures lower than this result in loss of mechanical strength but no rapid deterioration of the insulation. Thermal protective devices are available for use in dis-

tribution transformers which will eliminate the possibility of damage from this source. These devices, in the form of thermally operated circuit breakers, are placed in distribution transformers and adjusted so as to disconnect the transformer when the winding reaches a predetermined safe temperature.

It is apparent, therefore, that a great deal has been done in the design and construction of modern distribution transformers to prevent deterioration of any of the vital insulation members even after many years of service.

Until recent years, the accepted method of protecting distribution transformers against lightning was to connect lightning arresters to the primary leads and ground them to separately driven grounds. As pointed out by Mr. Sprague, the voltage to which the transformer was subjected was not only the discharge voltage of the arrester but the drop in the ground leads and in the ground resistance. Instead of limiting the voltage to 10 or 15 kv on a 2,400-volt transformer, it rose to 100,000 or 200,000 volts or more, depending on the grounding conditions and nature of the surges. Experiments have indicated the possibility of developing as high as 10,000 volts per linear foot in lightning arrester leads.

This represented the conditions in 1929 and 1930, when the 4 papers were written which were cited by Mr. Towne. These papers indicated the ratio of 2.5 as being ideal, and above which deterioration began. In this connection it is interesting to note that the first attempt to rationalize transformer insulation from the standpoint of surge voltages was made by Vogel in 1932 ("Factors Influencing the Insulation Coordination of Transformers," AIEE Transactions, volume 52, June 1932, page 411). Past experience with arresters having a ratio of 3.5 had reduced lightning troubles by 90 per cent. It is apparent that under the existing conditions it was only necessary to get more experience to determine that the ratio of 2.5 reduced the troubles due to lightning by only 90 per cent. The uncontrolled factors were the dominating ones in 10 per cent of the cases. In other words, lightning arresters protected against small induced surges but offered no protection against direct or near direct strokes. The introduction of balanced protection eliminated the uncertain factors of lead drop and ground resistance drop, and reduced the problem of lightning protection to a scientific basis. We are still confronted, however, with the problem of protecting apparatus against maximum conditions of surge voltages which have always been the cause of apparatus damage and system outages. This can be accomplished with protective devices, connected to give 3-point protection and having adequate surge current discharge capacity, which limit the voltage to a value below the breakdown strength of the insulation under all conditions. The curves in figure 3, assume this balance protection and show that the margin between the insulation strength and discharge voltage is satisfactory. Laboratory tests under direct stroke conditions prove this fact ("Direct Stroke Protection of Distribution Transformers," by H. V. Putman, *Electric Journal*, February 1937). Field experience confirms it.

It is difficult to compare a conventional valve type arrester with the deion arrester since they have such widely different characteristics. The deion arrester is essentially an arc-discharge device which bypasses the surge current. The lightning arrester on the other hand, is an energy absorbing device depending on the energy to establish the cut-off voltage. Some lightning arresters have a resistance discharge characteristic so that the discharge voltage increases with increasing current. It is not possible to determine the maximum voltage which would be sustained from the characteristics as determined by the relatively low AIEE test. The deion arrester, since it is an arc-discharge device, has a very low sustained voltage. It is equipped with a series resistor to prevent system disturbances in the cases when there is a flow of dynamic current following flashover. This resistor adds little to the sustained voltage under abnormal conditions since it is provided with a shunt gap which flashes over at high surge currents removing it from the path of the surge current. Under these conditions the deionizing action set up by the surge current appeases the establishment of any dynamic follow current. These devices are insulated to withstand and receive the AIEE acceptance dielectric tests for distribution transformers.

Mr. Towne has aptly stated that practical operating benefits have been pyramided over several years, as a result of a thorough study of the protection of distribution systems from lightning. It is believed that additional benefits can be derived by applying the knowledge so far gained on transformer insulation and the frequency and intensity of lightning stroke currents. We should not compromise on this problem but strive to protect apparatus against the maximum conditions to which it is subjected. As a protective ratio of 2.5 to 3.5 was considered adequate in the past when we had to deal with the uncertainty of lead and ground resistance drops, it would seem only logical that a higher ratio would be satisfactory with these uncertainties removed. This can be done without danger of apparatus failure, and would result in better system protection, better protection to the consumer through a more adequately insulated and a more rugged and serviceable protective device.

Distribution Lightning Arrester Performance Data

Discussion and closure of a paper prepared by the lightning arrester subcommittee of the AIEE committee on protective devices published in the May 1937 issue, pages 576–7, and presented for oral discussion at the lightning protective equipment session of the summer convention, Milwaukee, Wis., June 24, 1937.

Herman Halperin (Commonwealth Edison Company, Chicago, Ill.): The lightning arrester subcommittee also has prepared a general guide for use by utilities in testing lightning arresters. In this connection, the data on new arresters in the June 1937 Electrical Engineering will be found helpful. The guide should be of particular value in testing line-type arresters rated at 15 kv and less which are removed from lines.

For the past 4 years, we have been testing used 3-kv arresters in Chicago before they are returned to stock for reuse. About 85 per cent of those that were mechanically satisfactory have been found electrically suitable for additional service. These tests have all been made with 60-cycle supply.

In connection with the guide, it is hoped that some utilities will make impulse as well as 60-cycle tests in order to determine what correlation exists between the 2 types of tests in indicating defects.

L. G. Smith (Consolidated Gas, Electric Light, and Power Company of Baltimore, Baltimore, Md.): These data are of value and necessary in applying arresters intelligently. However, it is hoped that these data will be expanded in the future so as to cover additional lightning arrester characteristics so essential for the correct application of arresters. In view of the fact that solid insulation is subject to a wide range of surges including those of very steep wave front and those of very high current it is highly desirable to know the voltage that will be passed by the arrester for all types of surges, including those of very steep wave front and for surge currents up to the point at which the arrester element flashes over. The ideal application of lightning arresters is one in which the arrester will always fail before the equipment protected, since the arrester represents a much smaller economic loss than for that which it protects.

I. W. Gross (American Gas and Electric Company, New York, N. Y.): In this report on distribution arrester characteristics, we have for the first time, to my knowledge, a rather complete over-all picture of the expected performance of present day commercial distribution arresters.

A study of the data in table I shows that in the distribution arrester class *variations* in terminal voltage, both on initial breakdown, and under discharge conditions, of the order of 30 per cent may be expected. This situation which, I take it, is due largely to manufacturing tolerances which it is not feasible to overcome economically, should be recognized in applying lightning arrester protection not only to transformers of present design but also to those now in service, if satisfactory results are to be expected.

There is one thing that should be pointed out in connection with the impulse voltage permitted by these distribution arresters, and that is, they permit some 30 to 70 per cent higher voltage across their terminals on breakdown than they allow during discharge at 1,500 amperes. And yet these voltages at breakdown are at a comparatively low rate of voltage rise, namely, 50 to 100 kv per microsecond as specified in the present AIEE standards. These same standards provide for rates of rise of some 1,000 kv per microsecond in the 115- to 138-kv class of arresters. It is hard to believe that natural lightning is so temperamental that it impresses voltages of 1,000 kv per microsecond on high-voltage lines and takes pity on the distribution systems in the 3-

to 9-kv class and reduces its destructive effects to a 50 or 100 kv per microsecond pattern.

In addition I wish to suggest that all lightning arrester manufacturers give data on their arresters on a common basis, that is, on the basis of average, maximum, or minimum voltage characteristics both for breakdown and *IR*-drop characteristics, with expected tolerances stated.

In closing, it is hoped the committee will continue its work in collecting and presenting authentic data of this type on arresters in the higher voltage classes in both the distribution and station types. Such information is decidedly helpful in applying protection to equipment with a reasonable degree of certainty that it will work in actual practice. It cannot be too strongly emphasized that such data are absolutely necessary in attempting to apply the lightning arrester as a protective device to a great deal of the equipment now in use, where such equipment has been weakened with age, or of older design not having the insulation strength of apparatus bought today.

J. R. North: Mr. Gross's constructive suggestions regarding desirable improvements in the Institute Standards for Lightning Arresters and test procedure are most welcome. Table I in the report shows a wide range between the minimum and maximum performance characteristics of different makes of arresters. The gap breakdown voltage is of the order of 130–150 per cent of the average *IR* drop, with rates of rise of 50–100 kv per microsecond.

The voltage rating of arresters represents the maximum allowable dynamic voltage across the arrester terminals under any conditions. As mentioned by Mr. Halperin, reports prepared by the lightning arrester subcommittee discussing testing procedure, application of arresters, and specific protection practices have been prepared and will be distributed to members of the protective devices committee and other interested parties.

It is hoped next year to be able to present a report containing similar performance data pertaining to station type arresters and to line type arresters rated above 15 kv.

Expulsion Protective Gaps

Discussion and authors' closure of a paper by W. J. Rudge, Jr., and E. J. Wade published in the May 1937 issue, pages 551–7, and presented for oral discussion at the lightning protective equipment session of the summer convention, Milwaukee, Wis., June 24, 1937.

E. J. Allen (General Electric Company, Pittsfield, Mass.): The engineering data given in the paper sets forth the principal operating characteristics of expulsion gaps, based on 5 years' experience, and augmented by intensive development in the laboratory and field.

By way of explanation, the ordinate of the curves, on figure 10 in the paper, is plotted in terms of "length of flame feet" which, of course, is visible, and was scaled from photographs of staged tests. These photographs were taken during power current interruption of corresponding crest currents shown on abscissa. This "length of flame" versus "current" interrupted relationship is practically independent of circuit voltage rating.

Also of equal interest, however, is the length of electrically conducting gases within the flame during power current interruption by the tube. The length of electrically conducting gases is an important consideration when applying expulsion protective gaps in service, to prevent these expelled gases from contacting other nearby metal parts of dissimilar potential, and thereby avoiding risk of faulting other phases. For example, conducting gases from the line end of an expulsion tube should not come in contact with nearby grounded metal structures; likewise the gases from a design having a grounded end of the tube should not come in contact with any line conductors, which of course, are insulated from ground.

However, the proximity of metal objects to the path of the discharge gases is not as serious a limitation to the successful service applications of expulsion protective gaps as might be anticipated. Tests have shown that the length of the electrically conducting gases extending from the open end of the tube during power current interruption never exceeds the length of flame. For example, during field tests on a 132-kv system, a grounded metal pipe was located 6 feet, 10 inches from the "tee" discharge deflectors located on the line end of the tube. With this set-up during power current interruption of 11,300 crest amperes by the expulsion gap, the arc did not follow the flame to ground. At distances of 6 feet or less, a power arc was maintained between the discharge deflector and grounded metal pipe. At 11,300 crest amperes power current interruption, however, the length of flame is approximately 9 feet. Hence in this particular series of tests, the length of the electrically conducting gases extended only two-thirds of the distance between the "tee" vent and the visible length of flame.

Typical tests such as described above indicate that the length of electrically conducting gases within the flame envelope attending power current interruption by the tube bears a complex relationship, as this depends not only on the current, but mainly on circuit voltage characteristics and design of the discharge deflectors.

It is believed, therefore, that the curve, figure 10 in the paper, can be safely used when applying expulsion protective gaps to obtain adequate clearance from electrically conducting discharge gases, thereby avoiding risk of faulting other phases. In practice, the expulsion tube can either be positioned in such a way as to provide necessary clearance of discharge gases using straight vents from the tube or if not, the path of the expelled arc flame can be diverted by means of "tee" (90 degrees) or Y (45 degrees) discharge deflectors attached to the lower electrode.

Another point mentioned in the paper concerns the rapid expulsion action of the tubes, and resultant power current interruption before system relays can function. The "First Report of Power System Stability" by the AIEE subcommittee on interconnection and stability (Electrical Engineering, February 1937, page 261) recognizes that special tube-type protectors of a design described in the paper will increase the practical operating power limits.

System stability, or the ability of a system to stay together during a disturbance, is an important factor toward improving continuity of service. Line disturbances caused by lightning flashover of insulators with attendant load rejection will quite naturally tend to cause instability of transmission systems operating near the power limit. Even with ultrahigh-speed relaying and breakers on the faulted line, not equipped with protector tubes, the system is subjected to this disturbance for at least several cycles. Tests have shown that interruption of rated power current through an expulsion gap occurs within a cycle. Hence their net effect, by preventing flashover at the protected structures, is to reduce system outages and extend the stability limit, or power transmitting capacity of the system.

R. L. Thomas (Pennsylvania Water and Power Company, Baltimore, Md.): Too much emphasis cannot be placed on the statement made by the authors that proper mountings for expulsion gaps are absolutely vital. In a tabulation in the authors' paper there are statistics covering the operation of expulsion gaps on a 69-kv line of the Pennsylvania Water and Power Company in 1935 and 1936. Actually the statistics cover the line from Holtwood to Safe Harbor (Lehmans Farm switching station) owned by Pennsylvania Water and Power Company and the line from Safe Harbor to Lancaster (Engleside) which is owned by Pennsylvania Power and Light Company. The record for 1935 shows 4 tube failures and 16 trip-outs. A footnote states that "The cause for these failures has been determined and remedied."

Briefly, the remedies applied or changes made were first, the external gap was increased from 5 inches to 11 or 12 inches; second, a shielding ring was placed around the outside of each tube near the lower end; third, the horns were shortened; and fourth, an attachment was added to the mounting to prevent the turning of the tube mounting with respect to the insulator string and at the same time to allow the tube to swing with the insulator string.

There were no tube failures in 1936 and we thought the problem had been solved. However, on June 14, 1937 there was another tube failure. The circuit switches were reclosed 4 times but in each case there was another trip-out and the circuit was left out of service. It was several hours before the trouble could be located and remedied. It was found that on one of the tubes on a strain tower the fastening bolts had slipped in the slots provided for adjustment and that on this particular tube the horn had not been shortened sufficiently and the movement caused the horn to approach the conductor instead of increasing the external gap.

The failure shows the importance of carefully designed and ruggedly constructed mountings. Otherwise a device which is

intended to eliminate a large number of short time interruptions may actually cause a relatively long time interruption.

I do not want to introduce a note of discouragement since with any new device it is natural that all of the things that can happen cannot be foreseen. There were no tube failures in 1936 and naturally we hope that there will be no more in the future.

L. G. Smith (Consolidated Gas, Electric Light, and Power Company of Baltimore, Baltimore, Md.): The authors state as a requisite for the operation of these gaps that they have a lower flashover than the line insulation. While from a design standpoint this co-ordination is readily obtained, in actual installations care is necessary in that it is possible in the case of improper application to so distort the dielectric field that either co-ordination between the gap and the line insulation is destroyed or the co-ordination between internal and external flashover is lost. In tests it has been found that both of these are possible, namely, that external flashovers and insulation flashovers have resulted without an internal breakdown of the gap. The authors mention the possible use of these gaps on ungrounded neutral systems. Until more definite data are available on the ability of these gaps to clear the very low currents that would exist in the case of breakdown from phase to ground it is believed that such applications are questionable. In addition to this, should an arcing ground occur on one phase the voltage might rise to sufficiently high values on other phases to cause numerous tube flashovers.

The setting of the external gaps, particularly on lower-voltage tubes is quite important where the external gap is quite small. Our company, which has applied these tubes on 13.2-kv wood pole lines has had a few cases where expansion and contraction of the cross-arms due to alternate wetting and drying may account for as much as one-fourth inch change in dimension, thus causing the mountings to loosen and short the external gap. One case of tube failure attributed to this cause has actually been experienced. It is hoped that the possibility of trouble of this type has been eliminated by the change in the design of the mounting bracket, which includes 2 spurs which are forced into the crossarm. In addition to this some trouble has been experienced on strain poles where stranded line conductors were attached to the crossarm through strain insulators in which the the unwinding effect of the stranded conductor caused the strain insulators to rotate, moving the loop over the crossarm into the arcing rod, shorting the external gap. This trouble has been corrected by installing 2 pin-type insulators, one on each crossarm and relocating the tube so that the arcing rod points at the conductor between the pin type insulators, which carry the loop over the top of the crossarm.

While it is desirable to install expulsion protective gaps on every structure on high-voltage lines such a practice becomes quite expensive on low-voltage lines. If satisfactory operating results can be obtained a more economical installation would consist of installing these gaps on only a fraction of the total number of structures. In order to do this successfully it is necessary to have reasonably low ground resistance on those poles on which the gaps are installed and to maintain an insulation level as high as possible on those that do not have the gaps. As shown in table I in the paper we installed gaps on every second pole on one 2-circuit line and on every third pole on another line in 1935. In 1936 gaps were installed on another double circuit line on every fourth pole. No trip-outs due to lightning on any of these lines have been experienced. There was one trip-out due to tube failure resulting from shorting the external gap. There were 2 other cases of tube failure without trip-outs due to the shorting of the external gaps. In 1935 we installed a similar device of another manufacture on a single-circuit 13.2-kv line. In 2 years' operating experience no trip-outs due to lightning have occurred on this line. It is interesting to compare this operating experience with the operating experience prior to the installation of the gaps. On feeders number 87 and 88, the 3-year period prior to the installation of gaps in 1935, one feeder tripped out 5 times, 4 of which were due to burning down of the conductors and the other feeder tripped out 5 times, all 5 trip-outs, being due to conductor burndowns. On feeders 60 and 61 which were equipped with gaps on every fourth pole in 1936, in the 4-year period prior to 1936, one circuit had 7 conductor burn-downs and the other circuit 5, all due to lightning. In the single-circuit lines, which were equipped with tubes of another manufacture in 1935, this line tripped out 3 times due to lightning in the 3-year period prior to 1935. We plan to install devices of this kind on another double-circuit line with the tubes installed on every sixth pole. In all of these installations we are raising the impulse level of the ungapped poles to 700 kv. We are attempting to determine the maximum spacing of devices of this kind for use on 13.2 kv consistent with a material reduction in trip-outs. Obviously the lower the cost per mile for such installations the more miles of line that can be equipped.

It is believed that if satisfactory weathering characteristics are obtained with devices of this kind they have a real future in increasing reliability of service.

L. R. Ludwig (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): Messrs. Rudge and Wade presented in their paper a tabulation of operating companies who have utilized self-clearing protector tubes. The authors are correct in stating that the tubes have given very satisfactory results in the field. Attached is a list of further applications of these devices, which have been made during the past few years, also with satisfactory results.

The authors have stated that the problem of applying these protector devices is one of determining the short circuit currents and the recovery voltage. While it is relatively a simple matter to determine the short circuit current, the problem of determining the recovery rate is much more involved.

Mr. Evans and Mr. Montieth have made a very considerable contribution in this field by utilizing the calculating board in a novel manner for obtaining with the oscillograph an actual trace of the recovery voltage as it will occur on any given system.

Referring to the authors' figure 1, it is to be noted that the tube is of unsymmetrical design with respect to the electrodes. It would be expected that breakdown at the 2 polarities would be different on this account and the authors are requested to state if this is the case. Furthermore, since an inserted lower electrode has been omitted, it is conceivable that a certain amount of difficulty may be experienced with this design due to external flashover of the tube rather than internal flashover. It will be interesting to inquire if difficulties of this kind have been obtained.

H. G. Brinton (General Electric Company, Pittsfield, Mass.): In the case of oil circuit-breakers where the whole circuit is cut off, the value of capacitance may be quite small and the recovery rate very high but the device is capable of operating with very high recovery rates. On the other hand the safe operation of the expulsion gap calls for a less rapid recovery rate, but the recovery rates are lower because the circuit capacitance at interruption of the current is larger. Ordinarily the recovery rate on expulsion gaps is of the order of 100 to 300 volts per microsecond.

Figure 9 of the Rudge-Wade paper shows a sudden kick or rise in the arc voltage just before the arc broke, caused by a sudden increase of arc resistance. The arc voltage kicks up to about twice its previous value and the current drops to zero more rapidly. The voltage on the gap then reverses suddenly when the current comes to zero, be-

Table I. Installations of Deion Protectors, Type L

Customer	Location	Voltage (Kv)	Quantity	Date
Amtorg Trading Company	Russia	110	275	4/35
Cleveland Electric Illuminating Company	Cleveland, Ohio	34.5	244	5/33–10/35
Consolidated Gas and Electric	Baltimore, Md	13.8	285	3/35
Government of Puerto Rico (Water Resources)	Puerto Rico	33	250	2/34
Jersey Central Power and Light Company	Asbury Park, N. J	13.8	111	8/35
Loop River Public Power District	Columbus, Nebr	34.5	426	10/36
Management and Engineering Corporation	Dubuque, Ia	66	1,023	3/31
Milwaukee Electric Railway and Light	Milwaukee, Wis	132	500	12/33
Pennsylvania Power and Light Company	Allentown, Pa	69	385	3/35
Peoples Power Company	Davenport, Ia	66	222	2/35
Platte Valley Public Power and Irrigation District	Kearney, Neb	115	590	7/35
Platte Valley Public Power and Irrigation District	Grand Island, Neb	115	360	
Public Service Gas and Electric Company	Newark, N. J	33	850	1/34–2/35
Southern Ohio Power Company	Chillicothe, Ohio	69	150	2/36

cause the current was lagging and so the current and arc voltage were negative when the generated voltage was positive.

The voltage recovery rate in figure 9 is considerably steeper than that obtained in single gap line to ground operation where the current was smaller and more nearly in phase with the generated voltage. The more rapid recovery rates are usually associated with larger short circuit currents. It is an interesting characteristic of the expulsion gap that the larger currents and consequently greater evolution of exhaust gases enable it to clear with greater recovery voltages.

W. J. Rudge, Jr., and **E. J. Wade:** The discussions of our paper are particularly valuable in that they not only lay emphasis on the importance of many points mentioned in the paper, but add to the total operating experience which may be critically examined by those interested in the application of protector tubes.

Both Mr. Smith and Mr. Thomas have endorsed our statements as to the importance of properly mounting hardware for tubes. Mr. Smith's data on the comparative performance of feeders, both before and after they were equipped with tubes, is particularly helpful because it gives a better understanding of the improvement in line performance which can be obtained through their use. While from a theoretical point of view, tubes should be located on each structure to obtain best protection, Mr. Smith has shown that tubes located on every second, third, or fourth structure can effect a material improvement in line performance. This type of experience is needed by the industry, as it will enable an economic evaluation of the improvement in line performance which can be accomplished with different densities of installations. By employing such schemes it appears possible to effect a material improvement in line performance in a great many cases where economic considerations indicate that it is impractical to equip every structure.

Mr. Ludwig's discussion with the attached table is useful in that it gives an idea of the number of companies which are interested in the application of tubes. However, it is to be regretted that the data does not include the operating experience with the tubes, since tubes are comparatively new devices and it is necessary to build up a back log of experience which will be helpful in both the design and application of tubes.

The calculating-board methods described by Messrs. Evans and Monteith will no doubt be helpful in examining numerous circuit arrangements which cannot be easily obtained by field measurements. It must be realized, however, that before the calculating board results can be fully relied upon, that sufficient data from field tests on the actual circuits as they are in service must be obtained in order to establish the constants used on the calculating board. Experience in the past with models in the laboratory, particularly in the study of lightning, has shown that extreme care must be exercised when interrupting results obtained from studies on models rather than the full scale structures found in service. While we have made numerous calculations and studies of circuit recovery voltages, it is our feeling that greater confidence can be placed in the results by obtaining measurements on full scale models such as are found in service. It is for this reason that we have developed the equipment and pursued a program of making field tests to obtain this necessary fundamental information.

Mr. Ludwig has asked if the unsymmetrical design with respect to the tube electrodes caused by the omission of an inserted lower electrode is responsible for the external flashover of the tubes. Our tests to date have indicated that the insertion of a lower electrode alone does not carry with it the assurance that external flashovers will not obtain. It is truer, however, that the assembly and design do have an influence on the positive and negative impulse characteristics of the tube.

We wish to thank those who have taken part in the discussion of our paper and urge all operators who are obtaining experience with tubes to keep records on their performance so that they may be made available to the industry, as in this way a more complete picture may be had as to the relative merits of tubes and their ability to improve the performance of transmission circuits.

Flashover Characteristics of Rod Gaps and Insulators

Discussion of a report of the subcommittee on correlation of laboratory data of the EEI-NEMA joint committee on insulation co-ordination published in the June 1937 issue, pages 712–14, and presented for oral discussion at the lightning protective equipment session of the summer convention, Milwaukee, Wis., June 24, 1937.

C. S. Sprague (Purdue University, Lafayette, Ind.): This report presents data which are evidently the result of a considerable amount of work by 5 of the larger high-voltage laboratories of the country. The calibration of such easily reproducible apparatus as the insulator string and the rod gap should be of considerable advantage in checking the satisfactory operation of equipment and testing technique. Even though the insulator string and rod gap are rapidly losing caste as protective devices due to their impulse characteristics at very short times and the data is subject to a tolerance of 8 per cent, this does not seriously affect its usefulness for the above purpose.

Tables I and II show some apparent minor inconsistencies. For instance in table I, for suspension insulators with the 1×5 wave, the negative wave values are higher than those for the positive wave over the range of 12 units shown. With the 1.5×40 wave, the negative values are lower up to 12 units, at which points the curves apparently cross, the negative values being higher from 13 to 20 units.

However in table II for the rod gap, with the 1×5 wave the negative values are considerably higher except in the range from 8 to 20 inches where the positive and negative values are essentially the same, but with one point at 15 inches showing the negative value to be lower. For the 1.5×40 wave the negative values are considerably higher over the whole range, which is in contrast to the 1.5×40 wave data on the suspension insulators.

There is admittedly a considerable physical difference between the insulator string and the rod gap, and perhaps, in view of the 8 per cent tolerance, the above inconsistencies are more apparent than real. However, the writer would ask if there is, as yet, any satisfactory explanation of the preceding trends of the data of tables I and II.

In further reference to table I, will the 8 per cent tolerance apply to the values as given, for all 10-inch disks at $5^3/_4$-inch spacing, regardless of size or type of insulator cap and other hardware?

From figure 1, it appears that we now have a much needed correction for the effect of humidity. Years ago we talked of the relative humidity. Then there was found to be a correlation between spark-over values and the absolute humidity, and the latter was expressed sometimes as grams per cubic meter, and sometimes as grains per cubic foot. Now we have the correction factor plotted against the absolute pressure of the water vapor. While the writer has no particular preference as to how the water content of the air is expressed, it is hoped that a unified terminology can be adopted.

P. H. McAuley (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): A review at this time of the technical details leading to the satisfactory agreement in data from different laboratories seems appropriate. The outstanding items which contributed to this agreement are:

1. Use of cathode-ray oscillograph and resistance voltage divider as a method of voltage measurement.
2. Adoption of standard waves by all laboratories.
3. Determination of correction factors chiefly for humidity of the air.

Previous to 1929 the usual method of making high-voltage impulse tests was to set up a generator circuit, calculate the wave form by approximate methods and measure the peak voltage with a sphere gap. With the capacitors available, poor regulation naturally could not be avoided with changes in the capacity of the test piece. The importance of the oscillations due to generator inductance and stray capacity was not appreciated. These oscillations varied with load and resulted in inconsistent and abnormally high values. Fielder and Torok applied the cathode-

Table I. Comparing Early Trafford Impulse Data on Suspension Insulators With Values From the Committee Report

Units	1929	1937
4	425	440
6	605	610
8	780	780
10	945	945
12	1,105	1,105
14	1,260	1,265
16	1,425	1,425

ray oscillograph with a resistance voltage divider to a 2,000-kv impulse generator at Trafford in 1928. The practice of determining the volt-time characteristic curve of high-voltage insulation was adopted immediately and the sphere gap was practically discarded for impulse measurements. Our first field curve above 1,000 kv, dated November 1928, was on 10 suspension insulators and shows a minimum value of 920 kv and a one microsecond value of 1,510 kv. The most recently published data gives 945 and 1,500 kv for these points. However, this accuracy within 3 per cent in 1928 was partly due to compensating errors. The humidity was not even recorded but was probably around 0.15 inches of mercury. A 5 per cent positive error in the divider system was later discovered and probably compensated for most of the humidity correction. The wave form was far from smooth but the fundamental happened to be close to 1.5 × 40 and positive.

It is interesting to compare the values from the committee report with the time

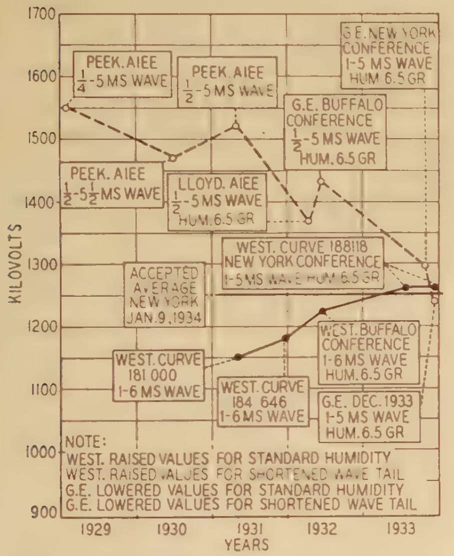


Figure 1. History of laboratory co-ordination; 11 standard insulators, positive short waves

log curves published in *Electrical World*, November 23, 1929 and in the AIEE TRANSACTIONS, July 1930. Insulators only are considered, as the present form of rod gap had not been adopted. The agreement in table I indicates the soundness of the measuring methods used at Trafford nearly 8 years ago.

A few years later this system of voltage measurement had benefited from a number of technical improvements chiefly on the cathode-ray oscillograph. Complete calibration curves for some of the sphere gaps based on measurements with the oscillograph were made and presented by Fielder (*Electrical World*, September 30, 1933). The effect of air conditions was realized and data on correction factors were collected. Standard waves were adopted in co-operation with other laboratories. Thus was made possible the correlation of laboratory data regardless of whether the sphere gap or the oscillograph was depended upon for voltage measurement. Many problems still remained and much time was required to collect and co-ordinate data on different apparatus. However, the technical obstacles had been solved experimentally. Then and not till then were reliable mathematical methods of impulse generator circuit analysis present.

The steps and progress in laboratory co-ordination are well illustrated by figure 1, showing different values obtained for minimum short wave flashover of 11 suspension insulators. Changes in wave form, humidity corrections, and measuring methods reduced a spread of 30 per cent to less than 2 per cent over a period of 3 years.

The trend at present to consider negative waves has introduced some more unknown factors and interesting problems. What seems to be needed now is fundamental research of the phenomena of breakdown.

Lightning Currents in 132-Kv Lines

Discussion of a paper by Philip Sporn and I. W. Gross published in the February 1937 issue, pages 245–52, and presented for oral discussion at the opening session of the North Eastern District meeting, Buffalo, N. Y., May 5, 1937.

P. L. Bellaschi: See discussion, this page.

S. K. Waldorf (Pennsylvania Water and Power Company, Baltimore, Md.): Analysis of a recent outage of the Holtwood-York 69-kv line has yielded information closely related to that presented by Messrs. Sporn and Gross. It has particular bearing on the questions of current distribution in transmission towers and the surge impedance of overhead ground wires.

One circuit of the double-circuit line tripped during a severe lightning storm. On patrolling the line, it was found that an arc had occurred between the top phase conductor and the structure of tower 63, and that the surge-crest ammeter links were strongly magnetized on towers 63 and 64. The links on towers 61 and 62 were found magnetized to a less extent. Brackets for the links were mounted on only one leg of each tower and indicated leg currents of 14,600 and 12,200 amperes in towers 63 and 64, respectively. As is customary when estimating the current in a tower equipped with only one pair of surge-crest ammeter links, the tower currents were taken as 4 times the leg currents, or 58,400 and 48,800 amperes in towers 63 and 64, respectively. The currents in the 2 towers being almost equal, it was concluded that lightning had probably struck one or both of the overhead ground wires between the towers.

With the footing resistance of tower 63 being 11 ohms, and the tower current 58,400 amperes, their product yielded a tower potential of approximately 640 kv. This was only about 60 per cent of the nominal flashover value of the line which indicated at first glance that the initial flashover should have occurred elsewhere than at the tower. Following this train of thought, the next possibility investigated was that of a flashover from a ground wire to the line conductor between towers, followed by flashover from the line conductor to tower 63. This seemed a likely sequence of events with the current of 58,400 amperes and the surge impedance of the overhead ground wire causing a potential difference of approximately 29,000 kv between the struck wire and the line conductor. Examination of lightning current observations made on 3 transmission lines since 1934 showed that this hypothesis also was probably incorrect. Numerous cases were found where heavy surge currents had travelled along overhead ground wires without flashover occurring. The circumstance has been repeated so often that the conclusion was inevitable that the surge impedance of an overhead ground wire is something appreciably less than 500 ohms at the point of contact of a lightning stroke.

Messrs. Sporn and Gross have shown that a relation exists between the length of a counterpoise conductor and its relative current-carrying capacity. At tower 63, 50 ohms was the ground resistance of the counterpoise connected to the leg in which the current of 14,600 amperes was measured, and the ground resistance of the other 3 counterpoise wires was 16, 20, and 55 ohms, respectively. The current in the tower was estimated on the assumption that the current carried by each leg varied inversely as the ground resistance of the buried conductor connected to that leg. On this basis, the current in the tower was calculated to be in the neighborhood of 110,000 amperes, which is more than enough to account for the flashover at the tower.

Measurements on towers having surge crest ammeter links on all four legs have shown that appreciable error in measurement can result if only one leg carries links, due to the unequal distribution of surge current between the legs of a tower. When all of the enumerated facts were considered, the conclusion was that the flashover was due to a very heavy surge current in tower 63.

In general, the analysis of this outage has led to an examination of the data collected by the Pennsylvania Water and Power Company from an additional point of view. At this time it is felt that Messrs. Sporn and Gross are correct in questioning the accepted value of 400 or 500 ohms as the surge impedence of a wire near the point of contact of a lightning stroke. Further investigation is being made to establish the effect of counterpoise ground resistance on the distribution of surge current in a tower.

Probable Outages of Shielded Transmission Lines

Discussion and author's closure of a paper by S. K. Waldorf published in the May 1937 issue, pages 597–600, and presented for oral discussion at the opening session of the North Eastern District meeting, Buffalo, N. Y., May 5, 1937.

P. L. Bellaschi (Westinghouse Electric & Manufacturing Company, Sharon, Pa.): The considerable field data on lightning currents now available naturally suggest through correlation processes the best design technique to render transmission lines

practically free from lightning outages. A great deal of laboratory and analytical work has been done to establish this development along sound lines. All this is clearly set forth in these 2 papers, yet it is apparent also that new data suggest further analysis. It is with this viewpoint in mind that a method is suggested for evaluating the duration of the lightning stroke discharge from the crest currents measured at adjacent towers.

Thus, lightning upon striking directly a tower of footing resistance R_1, discharges a current i_1 through it. Consider a current i_2 through the adjacent tower of footing resistance R_2. The inductance of the overhead wire or wires between the 2 towers is designated as L. The corresponding crest values of the currents measured at the two towers are, respectively, I_1 and I_2.

It has been established from fundamental findings, here and abroad, that the more common type of lightning discharge rises abruptly to crest, receding to low values in a relatively longer time (microseconds). The discharge is apparently unidirectional or quasi-unidirectional in wave form, though there are indications that reversal of the polarity of the current discharge may occur. The exponential wave form, when all is considered, is sufficiently valid for the purpose here and serves well as a first approach in the analysis. That is, considering that the current is

$$i_1 = I_1 e^{-\frac{0.69t}{T}} \tag{1}$$

it can be shown by relatively simple analysis that

$$i_2 = I_1 \left(\frac{R_1}{R_2}\right)\left(\frac{R_2/L}{R_2/L - \frac{0.69}{T}}\right) \times \left(e^{-\frac{0.69t}{T}} - e^{-\frac{R_2 t}{L}}\right) \tag{2}$$

The maximum current I_2 occurs at t_m, i.e.

$$t_m = \frac{\ln \frac{R_2}{L} - \ln \frac{0.69}{T}}{R_2/L - \frac{0.69}{T}} \tag{3}$$

Then

$$\frac{I_2}{I_1} \cdot \frac{R_2}{R_1} = \left(\frac{R_2/L}{R_2/L - \frac{0.69}{T}}\right) \times \left(e^{-\frac{0.69t_m}{T}} - e^{-\frac{R_2}{L}t_m}\right) \tag{4}$$

In applying relationship (4) it is essential that the crest currents should correspond to a lightning stroke directly to one of the towers. Considering values of transmission line constants encountered (such for example, $L = 400$ microhenries; $R_2 = 5$ to 20 or more), and since the ratio on the right hand of equation 4 would hardly or infrequently exceed 0.70 approximately, possible ranging down to 0.10, it appears from the equation that values of T (duration of lightning discharge) range from 10 to 100 microseconds.

Though this preliminary analysis in calculating the duration of the lightning-stroke discharge is subject to a number of obvious criticisms, these hardly should detract from the possibilities new analytical methods of attack present in the study of field data.

S. K. Waldorf: Mr. Bellaschi's conclusion that lightning surges are slower in development than has been generally supposed, is borne out by experience. There has been a lack of flashovers on overhead ground wires carrying heavy surge currents, a behavior probably due to the surge impedance of the ground wires being low as a result of the surges not having steep wave fronts.

Since table IV of the paper was prepared, the initial flashover of the Holtwood-York 69-kv line has occurred, which changes the actual lightning outages per year for this line from 0 as given in the table to approximately 0.5. This is in agreement with the value of 0.38 probable outages per year which calculation shows can be expected for this line. The other figures given in table IV remain approximately the same as originally given.

Heat Transfer Efficiency of Range Units

Discussion and author's closure of a paper by W. James Walsh published in the August 1937 issue, pages 953–8.

W. N. Lindblad (Pacific Gas and Electric Company, Emeryville, Calif.): Experience gained by the writer in making a number of tests such as Mr. Walsh describes has accentuated the importance of careful measurement and necessary compensation for errors in order that consistent results may be obtained. The use of a drop of oil to minimize evaporation is a unique and no doubt effective method of reducing this rather considerable error.

The over-all efficiency is greatly affected by the amount of water chosen. In a number of tests made by the writer on similar pots and units but with 5 pounds of water instead of 2.76 pounds, appreciably higher efficiencies were obtained. It would be of interest to know why Mr. Walsh selected 1,250 grams as the weight of water used.

The maximum instantaneous efficiencies were assumed by Mr. Walsh to be those coincident with the flat portion of the efficiency curves in figure 7 of Mr. Walsh's paper. It is to be noted that these efficiencies are occurring while the water and presumably the unit are increasing in temperature, possibly at the same rate. It has been the writer's experience that the unit continues to increase in temperature after the water reaches a constant temperature (boiling) and that, consequently, the heat transfer efficiency increases to a value somewhat higher than shown.

The increase in efficiency obtained with black-bottom pots, particularly on the more radiant units, coincides with the writer's experience. Other factors also have a bearing, particularly the concavity of the bottom. With a perfectly flat and bright-bottom pot, the writer has found that the unit B (as labeled in Mr. Walsh's paper) invariably showed higher efficiencies than unit A. When the flat bottom was blackened by spraying with lacquer, the efficiency on unit B was reduced considerably, showing that the heat conduction was reduced by the addition of the lacquer.

Tests with pots having a concavity of as little as $^1/_{32}$ inch gave results similar to those of Mr. Walsh's which leads the writer to believe that Mr. Walsh's pots were slightly concave.

It is interesting to note that with a perfectly flat top unit and a flat-bottom pot, over-all efficiencies of 67 per cent and instantaneous efficiencies of over 80 per cent were obtained with 5 pounds of water over a 75 degrees centigrade range of temperature.

W. J. Walsh: In regard to Mr. Lindblad's first remark, it may be stated that it was found quite possible to secure consistent results when a good oil film was formed over the water surface. However, there were times when, due to a slight surface contamination on the water, a film refused to form. This difficulty was remedied by taking greater pains in cleaning the equipment used in handling the water.

In connection with methods of minimizing evaporation, the device employed in similar tests performed recently at Oregon State College by Mr. W. G. Short may be of interest. In his tests, Mr. Short substituted a thin sheet of waxed paper (cut to fit the utensil at the water line) for the oil film, and secured even better results without the difficulties attending the use of oil.

In determining the amount of water to be used, the writer was guided principally by the apparent predominance of 2-quart utensils in ordinary cooking operations. In the writer's opinion, the use of larger quantities of water would result, in general, in slightly lower values of efficiency, supposing of course that the utensil diameter remained the same. Further, it appears to the writer that the efficiency values obtained with the larger quantities of water would depend to a great extent upon the ability of the temperature-indicating device employed to give truly representative average temperature values. To be more explicit, one would not use, say, a resistance thermometer with the resistance element spread out in only one plane, but one having the resistance element distributed in both horizontal and vertical planes. It seems reasonable to expect the latter device to give much more representative temperature values than the former when larger quantities of water are used. It would be of interest to know the method employed by Mr. Lindblad in determining his temperature values.

In his discussion, Mr. Lindblad further states that the writer assumed that the maximum instantaneous efficiency was coincident with the flat portion of the efficiency curves shown in figure 7 of the paper. This was not assumed, but definitely justified, as indicated in the paper under the heading "Discussion of Results" (page 957, Electrical Engineering, Aug. 1937).

Mr. Lindblad also indicates that in his experiments the use of lacquer on the bottom of the utensil reduced the efficiency of heat transfer of the unit labeled B in the

writer's paper. In this connection, it may be pointed out that the thickness of the lacquer layer and the condition of its surface would have a great deal to do with the results obtained. In the writer's experiments, results were obtained which indicated nearly a 3 per cent increase in the instantaneous efficiency of the unit *B* when it was used with the black-bottomed utensil. With a relatively thick layer of lacquer, it should be quite possible to effect a reduction in the efficiency of a unit such as *B*, but in the writer's opinion, a thin, dull-surfaced layer of lacquer would not result in an appreciable reduction in efficiency except on those units operating at a very low temperature.

Mr. Lindblad further points out that the concavity of the bottom of the utensil has a marked influence on the heat-transfer efficiency of surface units. It may also be pointed that a convex bottom has just as great, and probably a greater, effect. Since the utensils used by the writer were intended for actual kitchen use, they were purposely made slightly concave for obvious practical reasons.

In his closing statement, Mr. Lindblad cites certain efficiency values which he has obtained in his experiments. It would be very interesting to know the rating of the unit upon which the tests were performed, and the methods employed by Mr. Lindblad in determining the several necessary quantities involved. In short, a paper by Mr. Lindblad setting forth the results of his experience would be most welcome. The writer would like to take this opportunity to express his appreciation to Mr. Lindblad for his most instructive discussion.

The writer notes with considerable interest the presence of 2 letters to the editor in ELECTRICAL ENGINEERING for October 1937 commenting on the paper. Mr. Wiegand presents several interesting points which will undoubtedly be of value in future work along this line. Of course, the time and financial investment necessary for carrying out such tests as he proposes are practically beyond the range of any but a commercial organization.

The writer notes with particular interest the comments made by Professor Seeley in his letter. Essentially the same ideas were expressed to the writer by Professor F. O. McMillan of Oregon State College at the time that he suggested the subject to the writer.

Relay Operation During System Oscillations

Discussion of a paper by C. R. Mason published in the July 1937 issue, pages 823–32, and presented for oral discussion at the development of protective equipment session of the Pacific Coast convention, Spokane, Wash., August 31, 1937.

L. F. Kennedy (General Electric Company, Philadelphia, Pa.): It is my hope that every relay engineer will thoroughly study Mr. Mason's paper, particularly figures 5 and 6. Familiarity, with the changing relations between current and voltage, is necessary to an understanding of relay performance when the system is in a disturbed condition. We have known that protective systems, with the exception of the differential types, are more or less prone to operation during system swings or oscillations. Mr. Mason has presented the information bearing on relay operation in compact form for the benefit of relay engineers in such a manner that it should be of very material assistance to all relay engineers.

Supplementing the fundamental data showing system performance, Mr. Mason has indicated in general terms the manner in which various types of relay elements may operate. As he states, such conclusions as may be drawn are thorougly obvious from the text.

The use of zero-phase-sequence or negative-phase-sequence relay devices would eliminate any tendency to operate on oscillations or swings. Such relays will not operate to clear simultaneous 3-phase faults. It is most important that 3-phase faults be quickly removed if severe and prolonged oscillations are to be avoided. I have recently reviewed a number of oscillograph records of disturbances on a large Eastern system. A surprising number of these started as balanced 3-phase faults. I am in agreement with most protective engineers who feel justified in demanding that the protective equipment operate with at least the same degree of promptness on these balanced faults as on any other type.

J. H. Neher (Philadelphia Electric Company, Philadelphia, Pa.): Mr. Mason is to be congratulated on his excellent presentation of the complicated factors involved in the analysis of relay performance during out-of-step conditions on a transmission system.

In presenting the operating characteristics of the various types of relays involved, Mr. Mason has employed a somewhat different method than I have used in my paper. I should like to emphasize the point, therefore, that whichever method you prefer to use, that method is equally applicable in determining the performance of the relay under either out-of-step or fault conditions. In other words, the operation of a relay under short circuit conditions may be determined by applying the currents and voltages given in table I of my paper to the characteristic figures in Mr. Mason's paper, and, conversely, the impedance presented to the relay under out of step conditions as determined by Mr. Mason may be plotted against the characteristic impedance circle for the relay as I have described.

In this connection it is necessary to point out that equation 7 in Mr. Mason's paper gives the impedance presented to the relay as a scalar quantity, whereas it must be employed as a vector quantity in the graphical method which I have described. Equation 6 may be readily transformed into a vector expression for impedance and may be written using polar notation as follows:

$$Z\angle\phi_z = \pm\frac{Z^1}{2}\angle\phi_z' \times \left[(2n-1) - ctn\frac{\theta}{2}\angle 90°\right]$$

This equation when plotted for a given value of $Z'\angle\phi_z'$ and for all possible values of θ yields a series of parallel straight lines one for each value of n assumed. This is shown in figure 1 of this discussion in which the constants employed are the same as those in Mr. Mason's paper. The plus sign only of the equation has been used and the equivalent effect of the minus sign has

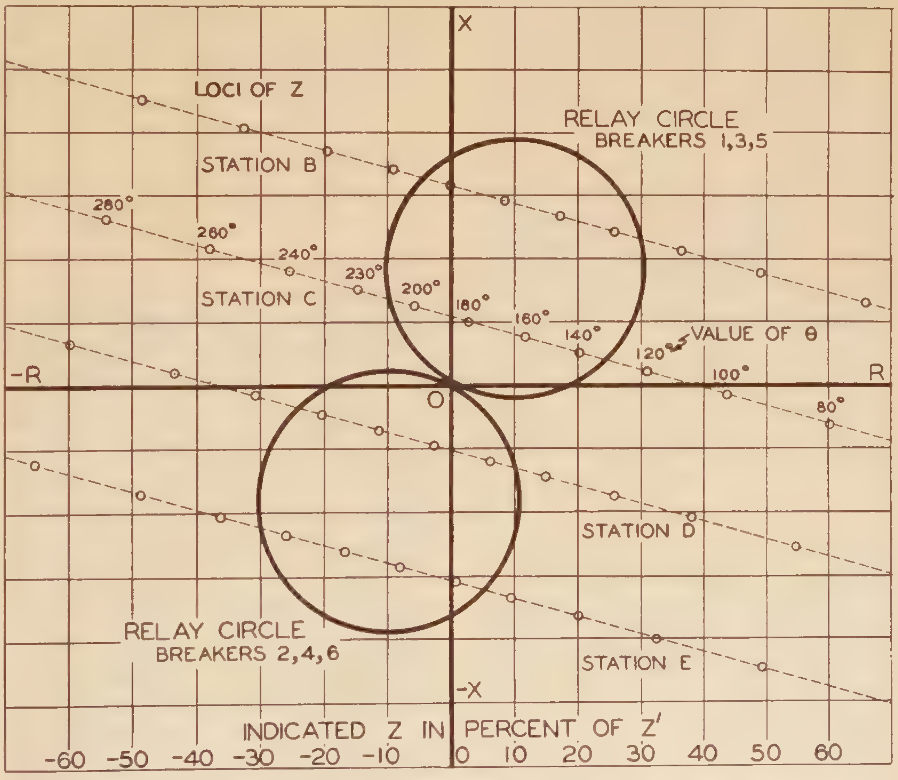


Figure 1. Impedance presented to distance relays during out-of-step conditions

been obtained by reversing the relay circle for breakers 2, 4, and 6. Considering the relay operation for breaker 3 at station *C*, as the system pulls out of step with source *A* leading source *F*, the impedance sweeps in from infinity on the right, passes through the relay circle shown (during which time the relay will operate) and then on to infinity on the left, very much in the manner of a comet. The relay operation at the other breakers may be illustrated in a similar manner.

The relay circles shown are those characteristic of directional elements with voltage restraint, but they may be drawn to fit the particular type of element and setting employed. The characteristic circle for a directional element without voltage restraint is a straight line passing through the origin drawn at a slope dependent upon its connections and its internal characteristic angle.

Capacitance Control of Voltage Distribution in Multibreak Breakers

Discussion of a paper by R. C. Van Sickle published in the August 1937 issue, pages 1018–24, and presented for oral discussion at the development of protective equipment session of the Pacific Coast convention, Spokane, Wash., August 31, 1937.

J. B. MacNeill (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The uneven distribution of voltage between breaks of a metal-tank circuit breaker has been known for several years. This unbalance is caused primarily by the relatively large electrostatic capacitance of the grounded tank relative to the capacitance of the contact parts. The voltage balance depends on the type of short circuit, whether grounded or ungrounded, as well as the spacings and capacitances of the parts involved.

It has been claimed by some that the unbalance referred to could not be disposed of in a commercial structure of the conventional type, and therefore radically different structures eliminating the metal tank have been proposed. This is not necessary, however, and the safety and ruggedness of the grounded tank still may be used, as shown by Mr. Van Sickle.

In 1929 and 1930 the general idea of using capacitance to balance that of the tank was used when the deion grids on the Plymouth Meeting 220-kv breakers of the Philadelphia Electric Company were designed with plate condensers in the upper units. Several other applications of the same principle have been since made.

The 3-cycle Boulder Dam 287-kv breakers required a more intensive application of the shunt capacitance principle, since over-all operation at this voltage made necessary complete duration of arcing of not over $1^1/_2$ cycles.

A paper in the AIEE for June 1937 by Wilcox and Leeds discussed these breakers and showed the performance well within 3 cycles on a 60-cycle basis can be expected during short circuit duty. Mr. Van Sickle's paper covers the methods of securing voltage distribution used in that design. The fact of proper distribution has been proved by several types of test:

1. Low-voltage electrostatic tests
2. High-voltage electrostatic tests
3. High-voltage dynamic tests using high-power laboratory

All 3 methods have borne out very closely the results expected from simple calculations of the electrostatic factors involved. Such calculations on a pure capacitance basis are slightly pessimistic, as the natural resistance characteristic of arcs in the interrupting devices tend to better the distribution.

Where exceedingly short times for switching are required at very high voltages, it must be conceded that some device to secure adequate distribution of voltage must be used. Recent claims for high speed at high voltages for devices which have inherently bad unbalance between breaks must be discounted as probably due to low rates of restored voltage. This will be seen if we look at figure 3 of Mr. Van Sickle's paper. Notice that in the curve for 8 breaks, the line break must handle 30 per cent of the total voltage across the pole unit, while on the other hand the last 4 breaks near ground total only 22 per cent, or less than the first single break. The tendency of the first break to re-establish an arc after current zero on a difficult high-voltage circuit is obvious.

On the other hand, figure 4 shows for 8 breaks that when proper devices for voltage balance are used, the first break handles only 16 per cent of the voltage across the pole unit, and the last 4 breaks average 10 per cent each and total 40 per cent of the pole unit voltage.

The design factors involved in very high speed, high-voltage breakers make these differences in voltage distribution a major factor in the ability of a design to handle difficult circuits, which at 230,000 volts or higher may have restored voltage rates of 4,000 to 6,000 volts per microsecond.

C. A. Powel (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): The multibreak circuit breaker is not new. Many years ago several manufacturers introduced various designs of such breakers but their performance was not strikingly better than that of ordinary 2-break breakers, in fact, generally not as good. In a paper presented to the first International Conference on High Voltage Systems in Paris in 1921, the writer pointed out that unless some means was found to reduce the total length of the arc, the volume of gas generated by a multiplicity of breaks was increased and arc interruption was made more difficult. A serious difficulty, which was not fully understood at the time, was the proper distribution, after current zero, of the voltage across the many breaks which tended to restrike and prevent extinction of the arcs. With the introduction of the "deion" grid, the arc energy and formation of gas was enormously reduced and the multibreak idea became interesting if an over-all opening time of less then 8 cycles, which had been reached with the conventional 2-break design, was required.

The difficulty of proper distribution of the voltage over the various breaks, however, still remained, and how it was solved is admirably explained in Mr. Van Sickle's paper. In the great majority of cases stability is the factor which determines the selection of breaker opening time, and the conventional 8-cycle breaker economically meets most operating requirements. In some few cases, however, a shorter time of opening can be justified and it is a satisfaction to know that where such an application proves economical, a design of breaker is available which is not radically different from that used for years.

The Ultrahigh-Speed Reclosing Expulsion Oil Circuit Breaker

Discussion and author's closure of a paper by A. C. Schwager published in the August 1937 issue, pages 968–70, and presented for oral discussion at the development of protective equipment session of the Pacific Coast convention, Spokane, Wash., August 31, 1937.

W. F. Skeats (General Electric Company, Philadelphia, Pa.): Mr. Schwager has developed a mechanism for making the complete opening and closing strokes of a 69-kv breaker within half a second. This will undoubtedly find an application in connection with interrupting devices which cannot be relied upon to clear appreciably before the end of the stroke and in cases where the shorter reclosing times which have been reported by other authors are not considered necessary. It appears, however, that this mechanism must complete its closing stroke before starting to open, so that the trip-free feature which is now applied very widely on large oil circuit breakers has been sacrificed.

In evaluating the tests which are listed, it would be interesting to know the interrupting capacity rating of the breakers tested. Without this information, it is not clear whether the tests were made on breakers of low interrupting capacity or whether the power available for testing was considerably less than the breaker rating. In the second case, while the tests no doubt establish the adequacy of the interrupting devices for the duty at which they are to be applied, it cannot be inferred without further proof that the interrupting capacity of the breaker is not modified by the short interval between interruptions.

It is noted that the duration of the second short circuit at figure 5 is approximately 14 cycles as against a little over 8 cycles for the first interruption. This is apparently due to the fact that in the second interruption was a closing-opening operation in which the breaker was delayed by the fact that the mechanism is not trip-free, but has to close all the way home before it can start to open.

A. C. Schwager: Mr. Skeats discusses the reclosing mechanism developed for 69-kv breakers and points out that the reclosing time of $^1/_2$ second is larger than that en-

countered on some more recently built mechanisms. The mechanism shown in figure 3 is the first motor-operated reclosing control installed in the United States and fully meets the requirements for which it was designed. It is believed that a control of this type will find application in a great many cases. However, in order to meet special requirements for still shorter reclosing times changes have been incorporated in more recent designs. These changes mainly consist of using a spring of smaller diameter, thereby reducing the moment of inertia and increasing the speed of operation. The duration of the second short circuit referred to in the third paragraph of Mr. Skeats' discussion (which in the case shown includes relay time) is thereby reduced to a value which is equal to or smaller than that obtained with any modern "trip free in any position" mechanism.

The short-circuiting tests described were performed on a 69-kv breaker which was equipped with expulsion contacts at the time of the installation of the control. The tests were not intended to be short-circuiting tests of the 1,000,000-kva breaker, but were to establish the performance of the breaker under fast reclosing service at maximum system load. The absence of carbonization and tank pressures indicate, however, that the breaker was stressed to a fraction of its full rating only.

The "trip free in any position " feature mentioned deserves a more detailed discussion. It is, of course, evident that the "electrically trip free" and "mechanically trip free" feature generally applied on breakers is retained in this mechanism. Mr. Skeats, in all probability, refers to the "trip free in any position of the closing stroke" feature.

This feature, in my opinion, has become of minor importance with the design of breakers using high-pressure contacts or butt-type contacts. Approximately one inch of travel is allowed in these breakers from the "contact touch" to the fully closed position. With the closing speeds used in present-day breakers, the blade cannot help but to go fully closed even if the breaker were tripped at the instant the contacts touch. With relays interposed it is even more impossible for these breakers not to go fully closed when closed into a short circuit. There are definite advantages in omitting the collapsible link which is normally identified with the term "trip free in any position" and which has been used on "modern" controls for the last 30 years. With its use the blade has to be accelerated by the opening spring exclusively whereas with the motor control described, the kinetic energy contained in the fast-moving spring is immediately and completely converted into opening speed.

Since modern arc-rupturing devices are dependent on operation above a definite minimum speed the use of this control gives assurance of fool-proof performance which cannot be expected of a breaker which has to be relied upon to accelerate in the part of the stroke where interruption should take place. In other words, the breaker cannot hang within the arc-rupturing devices.

It is believed that the intentional omission of the obsolete collapsible link mechanism is highly desirable from an operating standpoint alone, however, since it permits the design of such a mechanically simple and fool-proof control as described it seems to be doubly justified. Experience with this modern control will undoubtedly confirm this idea.

A Comprehensive Method of Determining the Performance of Distance Relays

Discussion and author's closure of a paper by J. H. Neher published in the July 1937 issue, pages 833–44, and presented for oral discussion at the development of protective equipment session of the Pacific Coast convention, Spokane, Wash., August 31, 1937.

L. F. Kennedy (General Electric Company, Philadelphia, Pa.): Mr. Neher deserves the thanks of all protective engineers for the work he has put forth in preparing the formulas included in table II. I have some idea of the vast amount of time necessary for its preparation. Many are familiar with the changes of distance relay indications between 3-phase faults and phase-to-phase faults when star-connected current transformers are used. Few, however, know the indications under all the conditions covered by this paper.

I am afraid that the author's work will not be made use of by many relay engineers because of lack of time and facilities for the necessary calculations. I should like to suggest that the formulas in table II be supplemented by actual figures for an assumed typical system. Such an effort would not represent a great amount of work in addition to that already done and would certainly make the author's efforts of real value.

C. R. Mason (General Electric Company, Schenectady, N. Y.): Some of your best friends are those you take the longest to get acquainted with. If you should feel that Mr. Neher's paper is a reticent sort of neighbor, I suggest that you proceed carefully but studiously toward making its acquaintance. It is my feeling that it will then be numbered among your choicest possessions.

Supplementing the excellent treatments by Lewis and Tippet and by Calabrese, Mr. Neher's paper sheds new light on the subject. Perhaps I should say light at a different angle. For, in this paper the conception of impedance at an angle is skillfully handled. For example, the operating characteristic of a relay which functions according to 3 variables, such as most distance and directional relays, is very conveniently drawn to 2 dimensions without parameters to confuse the picture. Then all possible types of faults are expressed in the same manner, and conveniently tabulated. This in itself represents a creditable contribution.

This method of treatment is particularly valuable when one is confronted by the problem of determining a new shape for a relay characteristic to fit certain special requirements. The requirements can be plotted in the form of impedance at an angle and then a relay curve or portions of curves can be drawn to fit the requirements. The methods of this paper thus operate conveniently either way—to find out how a given relay will operate under prescribed conditions or to devise a relay or a combination of relays to operate in a desired manner.

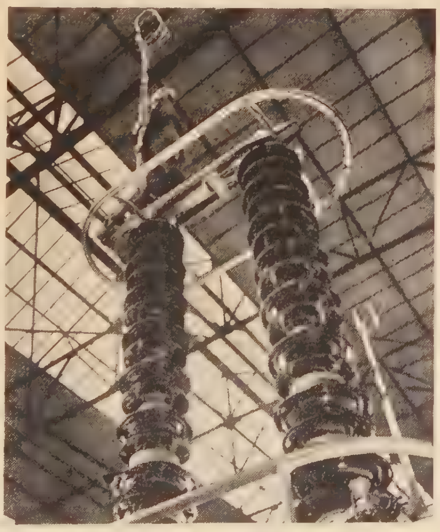
If a fourth variable, time, should be involved, this can still be cared for by the use of parameters.

Mr. Neher's methods provide a very powerful analytical tool which is well worth having on your work bench.

J. H. Neher: I wish to thank Messrs. Kennedy and Mason for their very kind remarks about this paper. I feel obliged to point out the fact, which was displayed too inconspicuously as a footnote in the printed copy, that I am indebted to their associate, Mr. Warrington for a good deal for which they are giving me credit.

Mr. Kennedy has suggested that the formulas in table II be supplemented by actual figures for an assumed typical system. I hesitate to do this because, as I have endeavored to point out, in some cases the impedance presented to a relay under a given fault condition is only a function of the effective line impedance between the relay and the point of fault, and in other cases it is dependent upon the system set-up as well. This can be determined by inspection of table II by noting whether or not the expressions for the impedance presented to the relay involve factors dependent upon the system set-up. In cases where the effect of system capacity is manifest, any figures which might be included based on an assumed system, would apply only to the particular system set-up assumed and might lead to erroneous conclusions if one were to generalize from them.

In preparing a paper of this kind the elimination of errors in the mathematical text is difficult. On page 834 directly below equation number 3 a square root sign should appear over the numerator of the expression given in the text for the radius of the circle. In table II the factors C and C' have been incorrectly printed in small letters in columns 5 and 8, lines 8 and 10. Also, in the first 2 lines of the seventh column a small z has been omitted in the denominators after the factor small c.



News

Of Institute and Related Activities

AIEE Winter Convention to Feature Enlarged Program

TO PROVIDE added interest for the specialist as well as the average member, an enlarged program of 16 technical sessions and 1 general interest session has been tentatively arranged for the 1938 AIEE winter convention, which will be held in New York, N. Y., January 24–28. Sessions will be held both mornings and afternoons beginning on Monday and continuing through Thursday. Friday, the fifth day, will be devoted exclusively to inspection trips to places of interest in the city and its environs. The main social events will consist of the smoker and the dinner-dance, which will be held in the evenings. In view of the popularity of last year's cruise, another post-convention cruise to Bermuda will be arranged by Leon V. Arnold. More information regarding these features will be announced in the January issue.

Technical Sessions

Of the 16 technical sessions tentatively arranged, 5 sessions are symposia. The symposium on modern electric vehicles will be held in both the morning and afternoon of the same day with interim for luncheon; the papers will deal with modern developments and experience with electric vehicles used in urban transportation. Similarly, two electronics symposia will be held: The first will treat the speed control of motors, and operating experience; the second, electronic applications and the slide-

Tentative Technical Program

In this program page references are given for papers that have been or will be published in ELECTRICAL ENGINEERING up to and including January 1938.

Communication

Coupling Between Parallel Earth-Return Circuits Under D-C Transient Conditions, **K. E. Gould**, Bell Telephone Laboratories, Inc.
September issue, pages 1159–64

*Printing Telegraph Operation of Way Wires, **G. S. Vernam**, Postal Telegraph-Cable Company.

*Electrical Remote Control Accounting, **L. F. Woodruff**, Massachusetts Institute of Technology.

A New Single-Channel Carrier Telephone System, **H. J. Fisher, M. L. Almquist**, and **R. H. Mills**, Bell Telephone Laboratories, Inc.
Scheduled for January issue

Symposium on Modern Electric Vehicles

Application of Modern Electric Vehicles to Urban Transportation, **C. M. Davis**, General Electric Company. Scheduled for January issue

Electrical Equipment for Modern Urban Surface Transit, **S. B. Cooper**, Westinghouse Electric & Manufacturing Company.
Scheduled for January issue

*General Features of the P.C.C. Car, **C. F. Hirshfeld**, Transit Research Corporation.

*Operating Experience With P.C.C. Car, **Thomas Fitzgerald**, Pittsburgh Railways Company.

Symposium on a New Carrier Telephone System for Toll Cable

Introductory Address: Broad-Band Wire Transmission Systems, **H. A. Affel**, Bell Telephone Laboratories, Inc.

*A Carrier Telephone System for Toll Cables, **C. W. Green** and **E. I. Green**, Bell Telephone Laboratories, Inc.

*Cable Carrier Telephone Terminals, **R. W. Chesnut, L. M. Ilgenfritz** and **A. Kenner**, Bell Telephone Laboratories, Inc.

*Crystal Channel Filters for the Cable Carrier System, **C. E. Lane**, Bell Telephone Laboratories, Inc.

*Cross Talk and Noise Features of the Cable Carrier System, **M. A. Weaver, R. S. Tucker**, and **P. S. Darnell**, Bell Telephone Laboratories, Inc.

Symposium on Modern Electric Vehicles—Continued

*Modern City Transportation, **E. J. McIlraith**, Chicago Surface Lines.

Modern Trolley-Coach Operation, **Edward Dana**, Boston Elevated Railway.
December issue, pages 1461–63

Modern Trolley-Coach Operation, **J. H. Polhemus**, Portland Electric Power Company.
December issue, pages 1483–86

*Operating Experience With Gas-Electric and Diesel-Electric Busses, **R. H. Stier**, Philadelphia Rapid Transit Company.

*Experience With Diesel-Electric Busses and All-Service Vehicles, **M. R. Boylan**, Public Service Coordinated Transport.

Lightning Protection

Characteristics of the New Station-Type Autovalve Lightning Arrester, **W. G. Roman**, Westinghouse Electric & Manufacturing Company.
July issue, pages 819–22

*Discharge Currents in Distribution Arresters—Part II, **K. B. McEachron** and **W. A. McMorris**, General Electric Company.

*Distribution Transformer Lightning Protection Practice, **L. G. Smith**, Consolidated Gas, Electric Light and Power Company.

Some Engineering Features of Petersen Coils and Their Application, **E. M. Hunter**, General Electric Company.
Scheduled for January issue

*Test and Operation of Petersen Coil on 100-Kv System of Public Service Company of Colorado, **W. D. Hardaway**, Public Service Company of Colorado, and **W. W. Lewis**, General Electric Company.

Symposium on Electronics—I

*Electronic Speed Control of Motors, **E. F. W. Alexanderson**, General Electric Company, **C. H. Willis**, Princeton University, and **M. A. Edwards**, General Electric Company.

Operating Experience With the Thyratron Motor, **A. H. Beiler**, American Gas and Electric Company. Scheduled for January issue

*Phanotron Rectifiers as a Direct Current Supply for Elevator Motors, **C. C. Clymer** and **R. G. Lorraine**, General Electric Company.

*Thyratron Control of Direct Current Motors, **G. W. Garman**, General Electric Company.

Relays and Reactors

A System Out of Step and Its Relay Requirements, **L. C. Crichton**, Westinghouse Electric & Manufacturing Company.
October issue, pages 1261–67

A High-Speed Distance-Type Carrier Pilot Relay System, **E. L. Harder, B. E. Lenehan**, and **S. L. Goldsborough**, Westinghouse Electric & Manufacturing Company.
Scheduled for January issue

*The Application and Performance of Carrier Current Relaying, **Philip Sporn** and **C. A. Muller**, American Gas and Electric Company.

Temperature Limits for Short-Time Overloads for Oil-Insulated Neutral Grounding Reactors and Transformers, **V. M. Montsinger**, General Electric Company.
Scheduled for January issue

*Harmonic Current Restrained Relays for Differential Protection, **L. F. Kennedy** and **C. D. Hayward**, General Electric Company.

*Some Schemes of Current-Limiting Reactor Applications, **F. H. Kierstead**, General Electric Company.

* Subject to approval for presentation, preprints of these papers will be made available. If ordered by mail, price 10¢ per copy. If purchased at headquarters, price 5¢ per copy.

back voltmeter, theater lighting, welding, and a new type of vacuum seal. The fifth symposium will deal with a new carrier telephone system for toll cable. Also in the communication field, there will be a general communication session and another session on the subject of television and broad band transmission. The remainder of the program is comprised of sessions on the subjects of lightning protection, relays and reactors, instruments and measurements, electric welding, basic sciences, power transmission, cables and research, and two sessions on electrical machinery. For the general session arrangements are being made to obtain a prominent speaker on a subject of broad interest to the engineering profession.

Technical Conferences

During the convention, technical conferences will be held on the subjects of education, field problems, network analysis and synthesis, electrical units, sound and vibration. The technical conferences are intended to afford opportunity for groups of specialists to meet and discuss subjects informally, no provision being made for the publication of the papers or the discussions in the TRANSACTIONS.

Rules on Presenting and Discussing Papers

At some of the technical sessions, a few papers may be presented only by title. This will permit the devotion of more time to discussion. At other sessions, papers will be presented in abstract, ten minutes being allowed for each paper unless otherwise arranged, or the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion. Authors will be notified officially in each case about one month in advance.

Any member is free to discuss any paper when the meeting is opened for general discussion. Usually five minutes is allowed to each discusser for the discussion of a single paper or of several papers on the same general subject. When a member signifies his desire to discuss several papers not dealing with the same general subject, he may be permitted to have a somewhat longer time.

It is preferable that a member who wishes to discuss a paper give his name in advance to the presiding officer of the session at which the paper is to be presented. Each discusser should step to the front of the room and announce, so that all may hear, his name and professional affiliations. Three typewritten copies of discussion prepared in advance should be left with the presiding officer.

Other discussions to be considered for publication must be submitted, typed double spaced, in triplicate to C. S. Rich, secretary, technical program committee, AIEE headquarters, 33 West 39th St., New York, N. Y., on or before February 11, 1938. Discussion received after this date will not be accepted.

The personnel of the 1938 winter convention committee is as follows: T. F. Barton, *chairman*, C. R. Beardsley, O. B. Blackwell, G. E. Dean, A. F. Dixon, E. E. Dorting, H. S. Osborne, C. S. Purnell, George Sutherland, and F. P. West.

Tentative Technical Program—Continued

Symposium on Electronics—II

*SHARP CUT-OFF IN VACUUM TUBES, WITH APPLICATIONS TO THE SLIDE-BACK VOLTMETER, **C. B. Aiken**, Purdue University, and **L. C. Birdsall**, Glencoe, Ill.

*THYRATRON REACTOR LIGHTING CONTROL, **E. D. Schneider**, General Electric Company.

*AN ELECTRONIC ARC-LENGTH MONITOR, **Walther Richter**, A. O. Smith Corporation.

*A NEW TYPE VACUUM SEAL, **W. E. Bahls**, Westinghouse Electric & Manufacturing Company.

Instruments and Measurements

*A NEW ALTERNATING-CURRENT NETWORK ANALYZER, **H. P. Kuehni** and **R. G. Lorraine**, General Electric Company.

*A STABILIZED AMPLIFIER FOR MEASUREMENT PURPOSES, **H. A. Thompson**, General Electric Company.

ELECTRICAL STUDIES OF LIVING TISSUE—II—CORRELATION BETWEEN TISSUE RESPONSE AND VOLTAGE DISTRIBUTION, **A. G. Conrad**, **H. W. Haggard**, and **B. R. Teare**, Yale University.
Scheduled for January issue

A NEW CORRELATION OF SPHERE GAP DATA, **D. W. Ver Planck**, Yale University.
Scheduled for January issue

Electric Welding

RECENT ADVANCES IN RESISTANCE WELDING, AIEE Resistance Welding Subcommittee, **C. L. Pfeiffer**, chairman. Scheduled for January issue

MECHANICAL HIGH-SPEED RESISTANCE-WELDER CONTROL, **F. H. Roby**, Square D Company.
September issue, pages 1145–48

*INTERPRETATION OF OSCILLOGRAMS OF ARC-WELDING GENERATORS IN TERMS OF WELDING PERFORMANCE, **K. L. Hansen**, Harnischfeger Corporation.

*THE RATING OF RESISTANCE-WELDING TRANSFORMERS, **C. E. Heitman**, Edward G. Budd Manufacturing Company.

Basic Sciences

MATRICES IN ENGINEERING, **L. A. Pipes**, The Rice Institute. September issue, pages 1177–90

*RESONANT NONLINEAR CONTROL CIRCUITS, **W. T. Thomson**, Alameda, Calif.

*SUBHARMONICS IN CIRCUITS CONTAINING IRON, **I. A. Travis** and **C. N. Weygandt**, University of Pennsylvania.

*THE PROPERTIES OF THREE-PHASE SYSTEMS DEDUCED WITH THE AID OF MATRICES, **M. B. Reed**, The University of Texas.

*CRITICAL CONDITIONS IN FERRO-RESONANCE, **P. H. Odessey** and **Ernst Weber**, The Polytechnic Institute of Brooklyn.

Power Transmission

*TRANSMISSION LINE TRANSIENTS IN MOTION PICTURES, **L. F. Woodruff**, Massachusetts Institute of Technology.

*LIGHTNING STRENGTH OF WOOD IN TRANSMISSION STRUCTURES, **Philip Sporn**, American Gas and Electric Company, and **J. T. Lusignan**, Ohio Brass Company.

*RECOVERY-VOLTAGE CHARACTERISTICS OF TYPICAL TRANSMISSION SYSTEMS AND RELATION TO PROTECTOR-TUBE APPLICATION, **R. D. Evans** and **A. C. Monteith**, Westinghouse Electric & Manufacturing Company.

SWITCHING SURGES WITH TRANSFORMER LOAD-RATIO CONTROL CONTACTORS, **L. F. Blume** and **L. V. Bewley**, General Electric Company.
December issue, pages 1464–75.

*SAFETY FEATURES FOR THE JOINT USE OF WOOD POLES CARRYING COMMUNICATION CIRCUITS AND POWER DISTRIBUTION CIRCUITS ABOVE 5,000 VOLTS, **J. O'R. Coleman**, Edison Electric Institute, and **A. H. Schirmer**, Bell Telephone Laboratories, Inc.

Electrical Machinery—I

CO-ORDINATION OF POWER TRANSFORMERS FOR STEEP-FRONT IMPULSE WAVES, **V. M. Montsinger**, General Electric Company.

CORONA VOLTAGES OF TYPICAL TRANSFORMER INSULATIONS UNDER OIL, **F. J. Vogel**, Westinghouse Electric & Manufacturing Company.
Scheduled for January issue

A FORMULA FOR THE REACTANCE OF THE INTERLEAVED COMPONENT, **H. B. Dwight** and **L. S. Dzung**, Massachusetts Institute of Technology
November issue, pages 1368–71

*STABILITY CHARACTERISTICS OF TURBINE GENERATORS, **C. Concordia**, **S. B. Crary**, and **J. M. Lyons**, General Electric Company.

Cables and Research

OIL OXIDATION IN IMPREGNATED PAPER, **J. B. Whitehead**, The Johns Hopkins University, and **T. B. Jones**, Bell Telephone Laboratories, Inc.
December issue, pages 1492–1502

*MECHANICAL UNIFORMITY OF PAPER-INSULATED CABLE, **K. S. Wyatt**, **D. L. Smart**, and **J. M. Reynar**, The Detroit Edison Company.

*THE CURRENT-CARRYING CAPACITY OF RUBBER-INSULATED CONDUCTORS, **S. J. Rosch**, Anaconda Wire & Cable Company.

SHORT-CIRCUIT PROTECTION OF DISTRIBUTION NETWORKS BY THE USE OF LIMITERS, **C. P. Xenis**, Consolidated Edison Company of New York, Inc.
September issue, pages 1191–96

Television

Address: CURRENT FIELD WORK IN TELEVISION **Ralph R. Beal**, Radio Corporation of America.

Address: NEW BROAD-BAND TELEPHONE SYSTEM **H. A. Affel**, Bell Telephone Laboratories, Inc.

Electrical Machinery—II

STRAY-LOAD LOSSES OF D-C MACHINES, **E. W. Schilling**, Michigan College of Mining and Technology, and **R. W. Koopman**, University of Kansas.
December issue, pages 1487–91

D-C MACHINE STRAY-LOAD-LOSS TESTS, **Victor Siegfried**, Worcester Polytechnic Institute.
October issue, pages 1285–89

UNSYMMETRICAL SHORT-CIRCUITS ON WATER-WHEEL GENERATORS UNDER CAPACITIVE LOADING, **C. F. Wagner**, Westinghouse Electric & Manufacturing Company. November issue, pages 1385–95

ALTERNATOR SHORT-CIRCUIT CURRENTS UNDER UNSYMMETRICAL TERMINAL CONDITIONS, **A. R. Miller** and **W. S. Weil, Jr.**, Lehigh University.
October issue, pages 1268–76

AIEE Board of Directors Meets at Institute Headquarters

THE regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on October 28, 1937.

There were present: *President*—W. H. Harrison, New York, N. Y. *Past-Presidents*—A. M. MacCutcheon, Cleveland, Ohio; J. B. Whitehead, Baltimore, Md. *Vice-Presidents*—O. B. Blackwell, New York, N. Y.; C. Francis Harding, Lafayette, Ind.; M. J. McHenry, Toronto, Ont.; I. Melville Stein, Philadelphia, Pa.; A. C. Stevens, Schenectady, N. Y.; Edwin D. Wood, Louisville, Ky. *Directors*—C. R. Beardsley, Brooklyn, N. Y.; V. Bush, Cambridge, Mass.; N. E. Funk, Philadelphia, Pa.; F. Ellis Johnson, Columbia, Mo.; C. R. Jones, New York, N. Y.; W. B. Kouwenhoven, Baltimore, Md.; F. H. Lane, Chicago, Ill.; K. B. McEachron, Pittsfield, Mass.; C. A. Powel, East Pittsburgh, Pa.; R. W. Sorensen, Pasadena, Calif. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y. Present by invitation: V. M. Montsinger, chairman, standards committee.

Minutes of the meeting of the board of directors held August 3, 1937, were approved.

Representatives and alternates of the Institute on other organizations were appointed as follows:

United Engineering Trustees, Inc.—for 4-year term beginning in October 1937: F. M. Farmer.

American Engineering Council Assembly—for calendar year 1938: C. O. Bickelhaupt, chairman, AIEE delegation; C. Francis Harding; William McClellan; C. E. Stephens; H. H. Henline, alternate. President W. H. Harrison is the fifth representative of the Institute, for the term August 1, 1937, to August 1, 1938.

Standards Council, ASA—for 3-year term beginning January 1, 1938: E. L. Moreland. Alternates for calendar year 1938: R. E. Hellmund; H. H. Henline; H. S. Osborne.

Engineers' Council for Professional Development—for 3-year term beginning in October 1937: F. Ellis Johnson.

The following were appointed for the year beginning August 1, 1937:

Committee of Apparatus Makers and Users, National Research Council: L. F. Adams.

Electrical Standards Committee, ASA (and, *ex-officio*, United States National Committee of the International Electrotechnical Commission): A. M. MacCutcheon; V. M. Montsinger; H. S. Osborne. Alternates: H. E. Farrer; R. E. Hellmund; E. L. Moreland.

Committee on Heat Transmission, National Research Council: T. S. Taylor.

Committee on Low Voltage Hazards, ASSE Engineering Section, National Safety Council: F. V. Magalhaes.

Electrical Committee, National Fire Protection Association: F. V. Magalhaes.

National Fire Waste Council: Wills Maclachlan, H. S. Warren.

It was decided to discontinue the appointment of representatives upon the following bodies, reports having been received of inactivity of the organization or of no further need for Institute representation: American Marine Standards Committee, and the Radio Advisory Committee of the National Bureau of Standards.

The following actions of the executive committee under date of September 20, 1937, were reported and confirmed: 4 applicants transferred to grade of Fellow; 20 applicants transferred and 7 elected to the grade of Member; 57 applicants elected to the grade of Associate; 32 Students enrolled.

Reports were presented and approved of meetings of the board of examiners held on September 16 and October 14, 1937. Upon recommendation of the board of examiners, the following actions were taken: 13 applicants were elected and one applicant was reinstated to the grade of Member; 50 applicants were elected to the grade of Associate; 843 Students were enrolled.

Monthly disbursements were reported by the finance committee and approved by the board of directors as follows: August, $24,804.67; September, $19,296.69; October, $35,234.32.

Upon the recommendation of the finance committee, the board authorized the transfer of the sum of $7,500 from last year's surplus in general funds to the reserve capital fund, and its investment in General Motors Acceptance Corporation bonds; and appropriated from last year's surplus the sum of $1,500 for the Institute's share of the cost of new book stacks for the Engineering Societies Library.

A budget, which had been prepared by the finance committee, was adopted for the appropriation year beginning October 1, 1937. Detailed budget information may be found on other pages in this issue.

The budget included provision for the re-establishment of cash prizes of $100 each for the national prize for initial paper and the national prize for Branch paper and of $25 each for the District prizes for initial papers, as recommended by the committee on award of Institute prizes if complete restoration this year of all cash prizes should not be considered practicable; also for the continuation of the cash prizes of $25 each for the District prizes for Branch papers.

A revised publication policy was adopted, as recommended by the publication committee. (Announcement was made in ELECTRICAL ENGINEERING for November 1937, page 1409.)

The chairman of the publication committee reported on the sales of the "Lightning Reference Book," which had been prepared by a subcommittee of the committee on power transmission and distribution and published by the AIEE. The sales indicate that the project will be self-sustaining.

Upon recommendation of the Section and District officers concerned, the board approved the dates, August 9–12, 1938, for the Pacific Coast convention to be held at Portland, Oregon.

Sections 81 and 68 of the by-laws were amended as follows, to bring them in accord with action of the board of directors, in June 1937, in approving certain recommendations of the committee on safety codes, which included a change in name of the committee to "committee on safety":

Section 81 changed to read:

Sec. 81. The committee on safety shall consist of 15 members, and shall consider and investigate matters relating to the protection of persons and property against hazard due to or resultant upon the presence of electricity or the use of electrical apparatus, material, and appliances, and shall report to the board of directors such recommendations thereon as it shall deem desirable for action by the Institute. To this end it shall encourage and co-ordinate safety considerations by other Institute committees in their respective fields, and with the approval of the board of directors, may arrange for co-operative relations with other bodies in the consideration of electrical hazard.

The first sentence of section 68 changed to read:

Sec. 68. The technical program committee shall consist of 9 members; and the chairman of each technical committee, the chairman of the committee on co-ordination of Institute activities, and the chairman of the committee on safety, *ex-officio*.

The following board members were selected to serve as members of the national nominating committee for the year 1937–1938: C. R. Beardsley, O. B. Blackwell, V. Bush, R. W. Sorensen, and A. C. Stevens. Mr. C. R. Jones was designated an alternate.

Upon recommendation of the standards committee, the board approved a revised edition of American Standard for Power Operated Radio Receiving Appliances, which had been submitted for approval by the Underwriters' Laboratories, proprietary sponsor for the project.

It was reported that, at the annual meeting of The Engineering Foundation on October 14, the budget for the fiscal year October 1, 1937, to September 30, 1938, was adopted, and it contained appropriations for research projects recommended by the AIEE, namely, stability of impregnated-paper insulation, and electric shock.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

Tulsa Section Holds Organization Meeting

Eighty-one members and guests attended the organization meeting of the AIEE Tulsa (Okla.) Section, October 18, 1937, which was authorized by the Institute's board of directors June 24. This is the Institute's 64th Section, the 63d having been organized recently at Wichita, Kans. Officers elected to take office immediately are: R. K. Lane (M'37) Public Service Company of Oklahoma, Tulsa, chairman; A. Naeter (A'23, M'30) Oklahoma Agricultural and Mechanical College, Stillwater, vice-chairman; and D. J. Tuepker (A'37) Public Service Company of Oklahoma, Tulsa, secretary.

H. L. Andrews (A'16, M'26) vice-president, General Electric Company, New York, N. Y., spoke on "Modern Transportation," a subject of wide interest as indicated by the discussion which followed.

Electricity Production Record. Production of electricity for public use in the United States reached a new high of 118,809,000,000 kilowatt-hours in the 12-month period ending September 30, 1937, the Federal Power Commission has reported. Total production in September was 9,985,000,000 kilowatt-hours as compared with 10,378,-

000,000 in August, which, on a comparable basis, is an increase of 7.2 per cent over September 1936. Average daily production in September was 332,833,000 kilowatt-hours, 0.2 per cent less than the average daily production in August. Production by water power in September was 32 per cent of the total. Considerable increases have been recorded every month this year over the same months in 1936. Electric-utility power plants consumed 4,030,059 net tons of coal in September 1937. Of this amount, 3,872,264 tons were bituminous coal and 157,795 tons were anthracite, decreases of 4.0 per cent and 1.6 per cent, respectively, when compared with consumption in the preceding month.

John Fritz Medal for 1937 Awarded to P. D. Merica

Paul Dyer Merica, director of research of the International Nickel Company and vice-president of the International Nickel Company of Canada, has been awarded the 1938 John Fritz Gold Medal, highest of American engineering honors, for "important contributions to the development of alloys for industrial uses." The award is made annually for notable scientific or industrial achievement by a board composed of representatives of the 4 national engineering societies of civil, mining and metallurgical, mechanical, and electrical engineers.

Doctor Merica's extensive research in theoretical and practical metallurgy has increased scientific knowledge in both ferrous and nonferrous fields, the citation of the board points out. "He has contributed generously to the science of metals, his work having covered the magnetic mechanical properties of steel; railway materials; failure of brass; the constitution, manufacture, and application of light alloys of aluminum; heat treatment of cast aluminum alloys; the precipitation theory of hardening of metals; and nickel and nickel alloys," it is declared.

Doctor Merica was born at Warsaw, Ind., on March 17, 1889. He studied from 1904 to 1907 at De Pauw University, which in 1934 conferred upon him the degree of doctor of science. In 1909 he received the bachelor of arts degree from the University of Wisconsin, and in 1914 the degree of doctor of philosophy from the University of Berlin. Following 5 years of work as research physicist in the United States Bureau of Standards, Doctor Merica in 1919 became director of research of the International Nickel Company. His home is at Millwood, N. Y.

He is a fellow of the American Association for the Advancement of Science, and a member of the American Chemical Society, the Electrochemical Society, the American Society for Testing Materials, the American Physical Society, the American Institute of Mining and Metallurgical Engineers, the American Institute of Civil Engineers, the Washington Academy of Sciences, the Institute of Metals, the Iron and Steel Institute, the Canadian Institute of Mining and Metallurgy, and Deutsche Gesellschaft für Metallkunde. He is the author of many articles and monographs in scientific and technical publications, and in 1929 received the James Douglas Medal.

Representatives of the AIEE on the board of award were J. B. Whitehead (A'00, F'12, past-president, Life Member), A. W. Berresford (A'94, F'14, past-president, member for life), and A. M. MacCutcheon (A'12, F'26, past-president).

Future AIEE Meetings

Winter Convention
New York, N. Y., January 24–28, 1938

North Eastern District Meeting
Pittsfield, Mass., May 1938

Summer Convention
Washington, D. C., June 20–24, 1938

Pacific Coast Convention
Portland, Ore., August 9–12, 1938

Southern District Meeting
Miami, Fla., November 1938

Noble Prize Awarded to Institute Member

For his paper "Properties of Saturants for Paper-Insulated Cables," G. M. L. Sommerman (A'31, M'37) research engineer, American Steel and Wire Company, Worcester, Mass., has been awarded the Alfred Noble prize for 1937. This paper was published in the May 1937 issue of Electrical Engineering, pages 566–76, and was presented for discussion at the AIEE 1937 summer convention held June 21-25 at Milwaukee, Wis. A biographical sketch of the recipient is included in the "Personal Items" section of this issue. Formal presentation of the award will take place at the AIEE 1938 winter convention to be held January 24–28 in New York, N. Y.

The Alfred Noble Prize was instituted in 1929 in honor of Alfred Noble, past-president of the American Society of Civil Engineers and the Western Society of Engineers, and consists of a $500 cash award and an engraved certificate. The award is made to a member of any grade of either the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, the American Institute of Electrical Engineers, or the Western Society of Engineers, for a technical paper of particular merit accepted by the publication committee of any of the foregoing societies for publication, in whole or in abstract, in any of their respective technical publications, provided the author, at the time the paper is accepted in practically its final form is not over 30 years of age. The recipient of the prize is selected by a committee of five members, consisting of one representative of each society, the award being based upon papers published by the societies within the 12 months preceding July 15 of each year. The first prize was awarded in 1931.

This is the third time that a member of the AIEE has been so honored, the 1932 award having gone to F. M. Starr (A'30, M'37) and the 1936 award to Abe Tilles (A'30, M'36).

A T & T Commemorates Works of G. A. Campbell

A volume entitled "Collected Papers of George Ashley Campbell" has just been privately printed by the American Telephone and Telegraph Company "in appreciation of Doctor Campbell's long and distinguished service, and of his fundamental contributions to the development of electrical communication." Commemorating Doctor Campbell's brilliant services to telephony, this 548-page (seven- by ten-inch) cloth-bound volume also marks his retirement from active service in the Bell System (*EE Jan. '36 p. 122*). In addition to three early memoranda on loading, the full text of some 21 of his noteworthy contributions to technical literature on communication over a period of more than 30 years are included.

In a foreword to the volume, Doctor Vannevar Bush (A'15, F'24) vice-president and dean of engineering of Massachusetts Institute of Technology, says of Doctor Campbell: "...he stands out as the one to whom the telephone art owes the realization of the loaded line, the electrical filter, and the facile treatment of the transients which pulsate in its network, and as a modest, generous character who by his very nature has inspired others to broaden into a highway the trail which he brilliantly blazed into the vast reaches of science and engineering."

Electrical Engineering appreciates being authorized to state that requests for copies of this commemorative volume will be entertained by the American Telephone and Telegraph Company, 195 Broadway, New York, N. Y., as long as the rather limited edition lasts.

Scholarship Available. The Elizabeth Clay Howald scholarship, which carries a stipend of $3,000 payable in 12 monthly installments, was endowed by the late Ferdinand Howald, an alumnus of The Ohio State University. Any person who has shown marked ability in some field of study and has in progress work, the results of which promise to constitute important additions to knowledge, shall be deemed eligible to appointment for this scholarship. The scholar will be expected to devote his time uninterruptedly to the pursuit of his investigation. If the scholar never has had any connection with The Ohio State University, he must carry on his investigations there; otherwise investigations may be carried on elsewhere. Applications must be filed with the dean of the graduate school of The Ohio State University, Columbus, before March 1, 1938. The appointment will be made on April 1, and the time of appointment will begin July 1.

National Research Council Continues Discussion of Insulation at New York Meeting

THE tenth annual meeting of the National Research Council's committee on electrical insulation of the division of engineering and industrial research attracted 144 registered guests and members of the committee for a two-day program devoted to the subject of dielectric research, November 4–5, at the Consolidated Edison Company building, New York, N. Y. Devoted to the interchange of information relative to many phases of dielectric research, this annual meeting, as usual, was notable in its unbiased attention to both the theoretical and practical aspects of the subject. The first technical session, devoted to the chemistry and physics of insulation, indicated clearly the increasing participation of the chemist and the physicist and the importance of their contributions in the solution of problems vitally important to both the manufacturer and user of electrical equipment. The committee, realizing the importance of co-ordination of the efforts of the chemist, physicist, and electrical engineer, is effectively contributing to many important advances by providing for the frank presentation of new problems and free, noncommercial discussions of products, manufacturing methods, and operating difficulties.

Representing the Consolidated Edison Company as official host, Doctor John C. Parker (A'04, F'12) vice-president of the company, delivered an address of welcome, encouraging the committee in the conduct of its work, and outlining what he termed the "selfish" interest of the electric power company in the work being carried on by the committee. Co-founder of the committee and continuing chairman, Doctor J. B. Whitehead, dean of the school of engineering of The Johns Hopkins University and past-president of the AIEE (1933–34), presided at the 3 technical sessions. W. F. Davidson (A'14, F'26), secretary of the committee, was chairman of the local committee on arrangements.

Among other features of the program were several informal group meetings for the discussion and outlining of special problems; the annual dinner meeting held Thursday evening at the Hotel Gramercy Park; a luncheon Friday noon, tendered by the Consolidated Edison Company; and several inspection trips to important plants and research laboratories located in the metropolitan area.

Atom Physics in Insulation Research

At the Thursday dinner meeting, a motion picture "Electrifying New York" was presented by the Consolidated Edison Company, and Professor A. von Hippel (M'37) Massachusetts Institute of Technology, delivered a lecture "What Can Atom Physics Contribute to Insulation Research?" Professor von Hippel's lecture revealed the importance of some of the fundamental investigations of the theoretical physicist in the domain of insulation research, and served to emphasize the value of a closer understanding between the physicist and others working in that field.

At the conclusion of the technical sessions a resolution to record in the minutes of the meeting the death (ELECTRICAL ENGINEERING for November 1937, pages 1427–28) of Henry Wright Fisher (A'95, M'01, F'12) former consulting engineer for the General Cable Corporation, and one of the pioneer cable engineers in the United States, was introduced by William A. Del Mar (A'06, M'20) and adopted unanimously by the committee.

Full Technical Program

Characterized throughout by spontaneous enthusiasm, the 3 technical sessions included a total of 21 papers, representing the efforts of 28 authors, and related discussions. Both the presentation of the papers and their discussions were entirely informal. For those readers interested in pursuing some of the subjects further, a complete list of titles and authors is given here. Although the committee expects that many of these papers will be published in various technical journals, so far only Doctor Whitehead's annual report and a paper by Doctors Whitehead and T. B. Jones have been published in ELECTRICAL ENGINEERING. Some few of the papers presented were extensions or continuations of papers presented at the meeting of the subcommittee on chemistry of the committee on insulation held recently at Rochester, N. Y., and reported in the November 1937 issue, page 1420. Others represented continuations of studies reported at previous meetings.

First Technical Session—Chemistry and Physics

RECENT PROGRESS IN DIELECTRIC RESEARCH (Annual Report of Chairman), J. B. Whitehead (A'00, F'12, past-president), The Johns Hopkins University, Baltimore, Md. [*November 1937 issue, pages 1346–52.*]

ELECTRICAL AND CHEMICAL STUDIES OF OIL OXIDATION, J. C. Balsbaugh (A'23, M'25), R. G. Larsen, and J. L. Oncley, Massachusetts Institute of Technology, Cambridge.

A continuation of a paper presented by one of the authors at the Rochester meeting of the subcommittee on chemistry, this paper presents relations between oxidation stability, acid formation, power factor, colloidal content, Grignard test, oil source, and refining methods. Many phenomena of the chemical and electrical aspects of this problem are still without any satisfactory explanation.

THE DIELECTRIC BEHAVIOR OF POLYMERIC MOLECULES IN DILUTE SOLUTION, J. W. Williams, University of Wisconsin, Madison.

Admittedly a highly theoretical approach of the chemist to dielectric theory, this progress report of work being done at the University of Wisconsin contributes to the general theory by a discussion of polymeric substances of high molecular weight, and shows evidence of dielectric polarization of such substances, principally in dilute solutions.

SOME RECENT STUDIES OF DIELECTRIC BEHAVIOR AND MOLECULAR ROTATION IN SOLIDS, C. P. Smyth, Princeton University, Princeton, N. J.

A correlation of dipole rotation in long-chain molecules with molecular size and with the dielectric constant of the material. This progress report of chemical research at Princeton University shows that solids consist of rod-like molecules with perpendicular axes; increased temperature causes rotation (change from the alpha to the beta form of the substance) and change of dielectric constant. For most substances the dipole moment is independent of frequency. "Small molecules,

Membership—

Mr. Institute Member:

The advantages of membership in the Institute have been emphasized in several excellent papers in ELECTRICAL ENGINEERING. The steady progress of the Institute is material testimony of its value. The services and opportunities it affords are numerous and varied. Some are attracted by its tangible benefits and direct services. Others are more interested in its general activities and opportunities for technical association and advancement of the electrical engineering profession.

You no doubt had definite reasons for joining the Institute. Why not tell one of your nonmember associates what they were and which of its services and opportunities you have found most valuable? You may give him an idea or viewpoint he has not previously considered which will induce him to join, and thereby receive the benefits he rightfully deserves as one connected with a branch of the electrical industry.

M. W. Smith

Vice-Chairman, District No. 2
National Membership Committee

because of their greater symmetry, are more likely to rotate in a crystal than are large molecules, but a large number of the latter have been found to give a high dielectric constant to the solid by their rotation."

Dielectric Properties of Chlorinated Naphthalenes, W. A. Yager, Bell Telephone Laboratories, Incorporated, New York, N. Y.

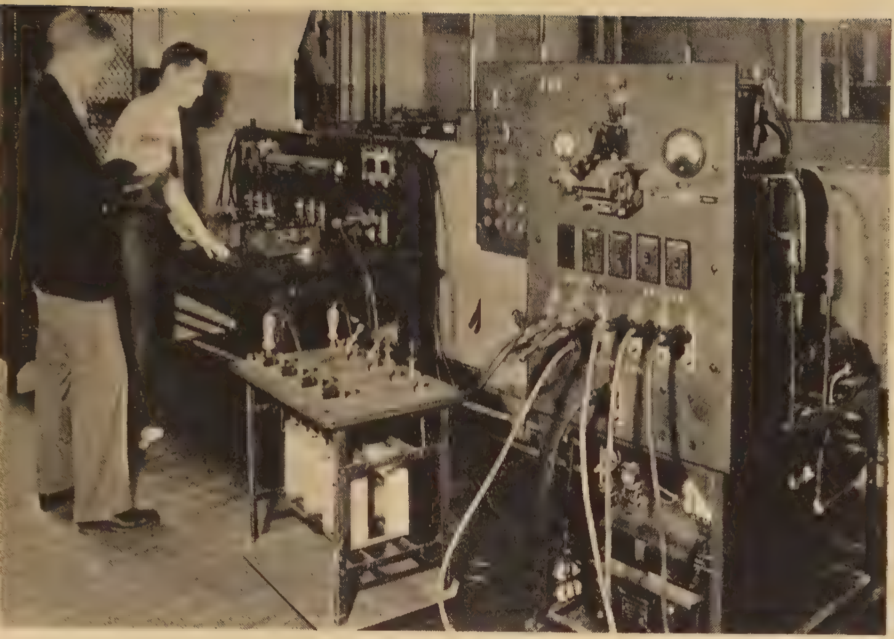
Investigation of the dielectric behavior of a commercial polar compound, a chlorine derivative of naphthalene.

Absorption of Water by Paper at High Temperatures, C. C. Houtz and D. A. McLean, Bell Telephone Laboratories, Incorporated, New York, N. Y.

Deals with the adsorption of water by insulating paper, instead of absorption indicated by the title. Aimed toward a better understanding of the fundamental nature of paper structure, the researches described produced adsorption data for various types of paper at various water-vapor pressures.

Further Studies of Deterioration in Insulating Oils, R. N. Evans, Consolidated Edison Company of New York, Inc., New York, N. Y.

Describing the methods of analysis of insulation deterioration as divisible into 3 classes (1) water evolution, (2) gas evolution and (3) miscellaneous, including electrical tests, this paper presents the results of studies based upon the second method, for predicting and analyzing cable failures caused by deterioration.



Allis-Chalmers Photo

A demountable metal-tank mercury-arc rectifier embodying the characteristics of commercial-size equipment is used in the study of electronics in the laboratories of Massachusetts Institute of Technology, Cambridge; similar equipment is said to have been installed at Cornell, Harvard, Columbia, and other colleges

Second Technical Session—Materials and Measurements

The Effect of Fillers on the Electrical Properties of Rubber-Sulphur Compounds, A. H. Scott, National Bureau of Standards, Washington, D. C.

In a continuation of previous studies undertaken by the National Bureau of Standards, methods of improving the preparation of specimens and of testing have been described. "The study of the effect of fillers on the electrical properties of rubber has so far been concerned only with spherulized "kaolin" (kaolin in the form of tiny spheres). With no kaolin the power factor was 0.0026 and the dielectric constant was 2.61. With 26.5 per cent of kaolin (by volume), the power factor was 0.0047 and the dielectric constant was 3.23. The d-c conductivity did not appear to be affected by kaolin. The dielectric constant decreased linearly with the logarithm of frequency and the power factor passed through a minimum as the frequency was increased."

Rubber as a Dielectric, A. R. Kemp, Bell Telephone Laboratories, Incorporated, New York, N. Y.

Dealing entirely with soft rubber compounds, "this report shows the extreme effect of moisture distributed heterogeneously in rubber in association with conducting substances on the dielectric properties. The loss in the insulating value of crude rubber upon exposure to water is explained on the basis of its latex particle structure with the impurities and moisture located in the particle interface forming a continuous phase . . . milling and vulcanizing crude rubber results in stabilizing its dielectric properties when the rubber is exposed to water. Rubber and gutta percha are shown to be nonpolar substances which are not appreciably affected by large contents of moisture." The effect of fillers and pigments on dielectric properties of soft vulcanized rubber are described.

Surface Characteristics of Fibrous Insulation, K. S. Wyatt (A'32), The Detroit Edison Company, Detroit, Mich., and W. F. Davidson (A'14, F'26), Consolidated Edison Company of New York, Inc., New York, N. Y.

Outlining some of the problems concerning utility operating companies in determining the characteristics contributing to failure of fiber insulation, the methods of failure are described, and several practical tests for analyzing and predetermining such failures are indicated. Following the formal presentation of the paper by Mr. Davidson, co-author Wyatt spoke briefly about the correlation between the amount of gas involved and the life of paper impregnated with oil, describing some of the European studies of the subject. Quoting Van Dycke, a research engineer at The Hague, Netherlands, Mr. Wyatt pointed out that "there is a correlation between life and gas generation as determined by the method with hydrogen pressure; in proportion as the gas generation of the oil is greater, the life of the paper impregnated with it is shorter. This correlation does not exist with the methods at low pressure."

The Effect of the Surfaces of the Electrodes on Power Factor of an Air Capacitor, A. V. Astin, National Bureau of Standards, Washington, D. C.

An extension of the National Bureau of Standards research work described at the 1936 meeting. Although no solid is included between the plates of an air capacitor, the capacitor has an appreciable power factor, because of surface characteristics of the plate. The 1936 report included investigations of only 4 materials for plates; the present paper, including a description of the effect of relative humidity on power factors, gives results for 10 materials. With aluminum plates a negative phase-defect angle at high humidity was observed, and was found to be more marked for large plate spacing than for smaller spacing.

The Power Factor of Air Capacitors, W. B. Kouwenhoven (A'06, F'34) and E. L. Lotz (Enrolled Student), The Johns Hopkins University, Baltimore, Md.

Although describing independent research work done at The Johns Hopkins University, scope is almost identical with preceding paper.

Thermal Breakdown of Plastic Insulating Materials, R. M. Fuoss, General Electric Company, Schenectady, N. Y.

A continuation of investigations described at the recent Rochester meeting of the subcommittee on chemistry, this investigation embraced changes of resistance with changes in voltage caused by thermal variation. The thermal failures observed were caused by passage of current alone, not by puncture, and were found to be independent of thickness of the sample.

Studies of Breakdown in Compressed Gases, Alvin Howell (A'35) Massachusetts Institute of Technology, Cambridge.

Describing the breakdown of compressed air at voltages up to 500 kv and at high pressures, using direct current exclusively. The breakdown characteristics of gaps having various surface configurations have been studied, the characteristics of a gap consisting of a needle point opposite a plane being especially important, because such gaps are used in the Van de Graaf generators constructed at MIT. Present investigations indicate that such generators will not work well in compressed air at pressures above 200 pounds per square inch. In general, generators using compressed air may be made much smaller than the open-air type.

Third Technical Session—High-Voltage Insulation

Measuring Rates of Oil Flow Through Paper, H. H. Race (A'24, M'31), General Electric Company, Schenectady, N. Y.

A description of the methods of measuring the rate of oil flow through flat sheets of paper in vacuum, to avoid inclusion of gas flow in the measurements. The method was extended to predict oil-flow characteristics by means of air-flow data.

Paper-to-Oil Ratio in Cables, E. W. Greenfield (A'34) Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y.

Because the ionization of power cables takes place in the voids in the insulation, the accurate determination of the most effective ratio of paper to voids is very important. Approaching these problems from a fundamental point of view, mathematical and experimental methods of determining the most effective arrangements of oil and paper layers are described.

Stability of Cable Oils Exposed to Electrical Discharge in Vacuum, W. A. Del Mar (A'06, F'20), John H. Palmer (A'29), and E. J. Merrill, Habirshaw Cable and Wire Corporation, Yonkers, N. Y.

A description of oil-stability characteristics during accelerated life tests as used on power cables. Oils having stable gassing characteristics usually have somewhat unstable power-factor characteristics under electrical discharge in vacuum.

Oil Oxidation in Impregnated Paper, J. B. Whitehead, The Johns Hopkins University, Baltimore, Md., and T. B. Jones, Bell Telephone Laboratories, Incorporated, New York, N. Y.

A report of a series of studies of the oxidation process in cable paper impregnated with oil containing different amounts of oxygen, as indicated by changes in well-known electrical quantities. Separate studies of the effect of equal amounts of air and of nitrogen, of the behavior of the oil alone, and as affected by paper and metal, show something about the nature of the progressive changes found in the electrical characteristics. [*See pages 1492–1502, this issue.*]

Stability of Oil-Treated Insulation, H. W. Bousman (A'25, M'36), General Electric Company, Schenectady, N. Y.

A long life test may not be the most important factor in judging an oil tor use in a cable, for the

"specific optical dispersion of oil is known to be related to the life of oil-impregnated paper."

ELECTRICAL CHARACTERISTICS OF IONIZED GAS FILMS, C. L. Dawes (A'12, F'35), Harvard University, Cambridge, Mass.

Describes methods of measuring characteristics of ionized gas films. A capacitance method was used instead of a mechanical method for determining thickness of the gas films.

MECHANICAL UNIFORMITY OF CABLE INSULATION AND METHODS FOR ITS MEASUREMENT, K. S. Wyatt, The Detroit Edison Company, Detroit, Mich.

Ionization at the low stresses used in cables must take place between the layers. This report describes a method of examining these interstices without mechanical deformation of the layers. The specimen is "embalmed" in styrene, and wafer-like samples sawed from the specimen are translucent, being easily examined without complex equipment. "The uniformity of most electrical characteristics is dependent upon mechanical uniformity of the cable."

The Institute Budget for the Year 1937-38

ALTHOUGH the members are familiar with the financial condition of the Institute, having seen the annual directors' report in the July issue of ELECTRICAL ENGINEERING, it is felt that many would appreciate a more detailed accounting of the $299,500 budget for the year ending September 30, 1938.

Accordingly, the following tabulation of estimated income and disbursements, adopted by the board of directors on October 28, 1937, is presented with comments which it is hoped will adequately explain the scope and purpose of those appropriations in which the membership is most vitally interested.

PUBLICATIONS

Electrical Engineering — Transactions. The budget provides for the publication of an increased number of technical-program papers and general-interest articles. During the last appropriation year, 1,594 pages were used and 1,785 pages are planned for the current year—an increase of about 12 per cent. The appropriation for this purpose is approximately $83,300 as compared with an expense of approximately $77,800 for the preceding year—an increase of about 7 per cent. Roughly two-thirds of the increased cost results from the increased number of pages, the remaining third resulting from increased circulation and higher material costs.

The study of publication policy undertaken by the publication committee about a year ago, has been completed, with the co-operation of the technical program committee, and the recommendations were acted upon at the October meeting of the board of directors. The budget as adopted is based on the recommended revisions in publication policy and includes an appropriation of $7,900 to provide preprints of the accepted manuscripts of all papers for national meetings and papers approved by the technical program committee for District meeting programs. A limited number of these preprints will be provided without charge for the use of authors and the technical committees. Others may purchase them for five cents each at headquarters and at the registration desk at meetings, or for ten cents each by mail. There will be published regularly in ELECTRICAL ENGINEERING a list of preprints available.

Other provisions of the revised publication policy and the budget call for the publication in full in ELECTRICAL ENGINEERING of two-thirds of all technical-program papers and for the publication in ELECTRICAL ENGINEERING of the other third in "rewrite" or "abstract" form. TRANSACTIONS will include all formal technical-program papers in full and correlated with the approved discussions. Notwithstanding the increased number of pages and the increased material costs, the subscription price of TRANSACTIONS will be $4.00 as it has been in the recent past.

Additional information concerning the revised publication policy will be found in the November 1937 issue of ELECTRICAL ENGINEERING, page 1409.

Yearbook. An up-to-date revision of the YEARBOOK will be issued again this year and the budget includes approximately $6,800 for this purpose. Copies of the YEARBOOK are available without charge to members on request. An announcement will appear in the news columns of ELECTRICAL ENGINEERING when the book is ready for distribution.

INSTITUTE MEETINGS

In conjunction with the publication of technical papers and discussions, the national and District meetings of the Institute, as well as the meetings of Sections, provide the greatest opportunity for the realization of Institute objectives. In organization work—whether it be social, political, trade, or the work of a professional group similar to the Institute—effectiveness of operation is measured to a great extent by the membership contact provided.

The appropriation for meetings' activities for the coming year is intended to cover particularly the routine printing and supplies expenses of the Middle Eastern District meeting, which was held in Akron, Ohio, October 13–15, 1937, the winter convention in New York City, January 24–28, 1938, the North Eastern District meeting to be held in Pittsfield, Mass., in May, the summer convention in Washington, D. C., June 20–24, 1938, and the Pacific Coast convention which will be held in Portland, Oregon, August 9–12, 1938. In addition, the appropriation takes care of those expenses of the 1937 Pacific Coast convention which were not reimbursed until after accounts were closed for the 1936–37 year, as well as routine expenses incurred at Institute headquarters and chargeable directly to meetings' activities.

In considering the amount appropriated for Institute meetings, attention must also be given to the provision for traveling expenses of Section and Branch delegates (see paragraph dealing with traveling expenses) who, together with the officers and members in attendance at the summer convention, hold an annual conference for the interchange of ideas and experiences. Of late years the scope of these conferences has broadened so that a considerable part of the discussion deals with topics of interest not only to members residing within Section territory but to the entire membership—in many cases the recommendations of the conference leading to the adoption of policies which are expected to enhance the benefits of membership and the usefulness of the organization.

INSTITUTE SECTIONS

The major portion of the appropriation for Institute Sections is intended to cover the expenses of meetings as held during the year by 64 Section organizations. The By-Laws provide for a flat appropriation of $175 for each Section, plus an allowance of $1 for each active member residing within the territory of the Section on August 1.

As shown in the tabulation, other expenditures, charged directly to Institute Sections, comprise the cost of printing and supplies furnished by headquarters throughout the year, and that proportion of the headquarters' staff payroll which is allocated to Section activities.

INSTITUTE BRANCHES

One hundred twenty Branches of the Institute are now established in schools of recognized standing throughout the country, where students hold regular meetings, as do the members in Institute Sections. The budget provides for the reimbursement of purely meeting expenses, the cost of necessary supplies for carrying on routine Branch work, and that portion of salary expense at headquarters which represents the time entirely devoted to Branch activities.

The appropriation for Institute Branches also provides for the reimbursemnt of miscellaneous expenses which develop incidental to Student conferences and conventions. Payments are not made to the individual Branches but to the committee in charge of a conference and cover the actual expenditures within a limitation of an appropriation of $5 for each Branch participating in the meeting.

COMMITTEES

In view of the official record of Institute activities, as contained in the monthly journal, ELECTRICAL ENGINEERING, it is probably unnecessary to dwell upon the scope of the appropriations for the different committees of the organization. Nevertheless, a few comments regarding the larger appropriations may be of interest, as follows:

Finance Committee. For the third consecutive year the budget provides for the

engagement of investment counsel services, in an effort to insure the stability and security of Institute investments for the reserve capital fund, as well as for the special funds for which the Institute has accepted the responsibility of trusteeship. In addition, the appropriation takes care of the expense of the annual audit of Institute accounts for the fiscal year ending April 30, a report of which appears in ELECTRICAL ENGINEERING for July 1937.

Membership Committee. The work of this committee in bringing the advantages of membership to the attention of desirable candidates continues along much the same lines each year; therefore, a considerable portion of the committee's appropriation is devoted to the printing of necessary application forms and other membership literature describing the aims of the Institute. The distribution of this literature is handled almost entirely by the 64 local Section membership committees under the general direction of the national committee.

As shown in the annual report of the board of directors, 1,756 new applications were received during the last fiscal year, many from persons whose names were proposed for membership as a result of the communications addressed by the national committee to the general membership. The expense of the clerical work at headquarters in handling these applications, as well as the routine correspondence with Section membership committees, with members concerning the status of their affiliations, with Enrolled Students eligible for advancement to the Associate grade, etc., constitutes a charge to the appropriation. One other item is worthy of mention, i.e., the special payment of a portion of the entrance fee to the Section in which a new member is located, estimated to require this year at least $1,400 of the committee's appropriation.

Standards Committee. The activities of the standards committee for the past year have been so fully related in the annual report of the board of directors published in the July issue of ELECTRICAL ENGINEERING that further comment should perhaps be confined to the plans of the committee for the revision and printing of new editions of 11 standards, as mentioned below:

Measurement of Test Voltages in Dielectric Tests
Industrial Control Apparatus
Graphical Symbols
Automatic Stations
Electrical Measuring Instruments
Insulators
Indicating Instruments
Electrical Recording Instruments
Electrical Installations on Shipboard
Test Code for D-C Machines
Test Code for Apparatus Noise Measurement

The preliminary expense for composition and other printing expenses on account of the above-mentioned revisions will be charged to the appropriation of the standards committee, in addition to any miscellaneous charges and that portion of the headquarters' payroll which reflects the time devoted to the work of the committee.

Technical Committees. It has not been necessary to make separate appropriations for the technical committees inasmuch as all of the expenses of printing technical papers, under existing publication policies, has been chargeable to the publication committee. A nominal appropriation of $250, therefore, covers principally the expense of providing committee stationery and also minor expenses which will arise during the year. However, with the inauguration of the plan to reproduce authors' manuscripts, already mentioned, it is probable that $1,000 of the appropriation of $7,900 for such preprints will be transferred to the appropriation for technical committees, for use in reproducing those papers which are not intended for publication in the annual TRANSACTIONS.

TRAVELING EXPENSES

The budget again provides for reimbursement of substantially all the expense incurred for railroad fare, Pullman accommodations and meals en route, in the traveling allowance to District, Section, and Branch representatives, to members of the board of directors, and to members of the national nominating committee. The traveling allowances are reimbursed on a uniform rate of 7 1/2 cents per mile, one way, mileage being obtained from the Official Table of Distances compiled by the United States War Department. The authorized traveling expense appropriations are as follows:

1. For each vice-president of the Institute to one meeting each year of each Section and each Student Branch within his geographical District, it being understood that joint meetings of Sections and Branches will be arranged as far as may be expedient.

2. For the vice-president, the District secretary, the vice-chairman of the national membership committee located in the District, the chairman of the District committee on Student activities, and the chairman and secretary of each Section within a District (or, if neither can attend, an alternate chosen by the executive committee of the Section) to one meeting each year of the District executive committee held within the District.

3. For the vice-president and secretary of each District, the counselor and the incoming Student chairman of each Branch within the District, and the appointed member of the committee on Student Branches located in the District to one conference on Student activities within the District each year under the auspices of the committee on Student activities of the District. Alternates for counselors not authorized. The allowance is available to alternates for Branch chairmen only upon advance approval by the vice-president of the District in each case.

4. For one delegate from each Section to the annual summer convention.

5. For all District secretaries to the annual summer convention.

6. For one Student Branch counselor from each District, to represent the committee on Student activities of the District, to the annual summer convention.

7. For all members of the national nominating committee to the annual meeting of the committee, held during the winter convention.

Table I. Institute Income and Expenses for Year Ending September 30, 1937, and Budget for Year Ending September 30, 1938

	Actual Income and Expenses, Year Ending 9–30–37	Budget for Year Ending 9–30–38
Income		
Dues	$195,963.61	$207,300.00
Students' fees	11,028.00	11,000.00
Entrance fees	7,468.15	7,000.00
Transfer fees	855.25	1,000.00
Advertising	33,602.31	35,000.00
ELEC. ENGG.—nonmem. subscriptions	13,700.56	14,000.00
TRANS. subscriptions	6,058.52	5,750.00
Miscellaneous sales	9,977.01	7,000.00
Badge sales	1,752.21	1,750.00
Interest on securities	9,109.52	9,700.00
Total	$289,515.14	$299,500.00
Expenses		
Publications		
Text matter (ELEC. ENGG. & TRANS.)	$77,803.40	$83,320.00
Preprints		7,900.00
Advertising section	14,146.94	15,600.00
Year book	6,195.93	6,760.00
Institute meetings	12,020.41	13,960.00
Institute Sections		
Appropriations	21,051.68	25,000.00
Other expenses	5,477.32	6,050.00
Institute Branches		
Meetings expenses	897.62	1,000.00
Other expenses	2,001.15	2,300.00
Committees		
Finance	1,600.00	1,600.00
Membership	8,000.46	8,300.00
Standards	6,475.58	7,700.00
Technical	201.44	250.00
Others	198.53	1,175.00
Traveling Expenses		
Geo. Dist. exec. committees	1,620.48	3,000.00
Section delegates to summer conv.	3,861.14	5,000.00
Counselor del. to summer conv.	760.21	750.00
Dist. secys. to summer conv.	574.96	900.00
District Student conferences	6,407.15	6,500.00
President's appropriation	2,312.82	1,500.00
Vice-presidents	227.60	750.00
Board of directors	4,690.60	6,000.00
National nominating com.	907.38	1,000.00
Institute representatives		100.00
Administration		
Headquarters' salaries	32,994.72	36,990.00
Postage	3,294.66	3,500.00
Stationery & printing	3,427.24	3,600.00
Office equipment	181.03	250.00
Trav. expense, insurance, misc. supplies & services	2,933.40	2,950.00
Paper prizes	140.00	600.00
Joint activities		
Amer. Engg. Council	12,000.00	12,000.00
Amer. Standards Assn.	1,375.00	1,500.00
Engrs. Council Prof. Dev.	450.00	850.00
Engg. Soc. Employment Serv.	1,964.40	1,162.00
Engg. Societies Library	8,788.20	9,700.00
United Engg. Trustees building assessment	9,740.13	10,882.00
U. S. Natl. Com. I.C.I.	300.00	300.00
Miscellaneous printing, etc.		3,500.00
Authors' reprints	1,628.70	....
Reprints of standards	815.11	....
Lightning Reference Book	4,964.88	..
Miscellaneous	223.24	..
Other expenses		
Membership badges	1,709.71	1,750.00
Text paper & env. in storage	1,251.10	....
Retirement salary	2,700.00	2,700.00
Miscellaneous	416.18	310.00
Total	$268,730.50	$298,959.00

8. For members of the board of directors and the executive committee to meetings of the respective bodies.

It will be noted that the traveling expense allowance has been restored for both the chairman and secretary of each Section within a District in attendance at the annual meeting of the District executive committee, whereas the budget allowance during recent years provided for the attendance of but one representative from each Section. In addition, an allowance for traveling expense has been provided to the vice-chairman of the national membership committee, who is now a member of the executive committee in his respective geographical District.

Administration

The duties of the headquarters staff being closely interwoven with the activities of the 24 standing administrative committees and 18 technical committees, it is easy to understand the allocation to this appropriation of approximately 41 per cent of the total of salaries paid to those members of the staff whose compensation is not chargeable elsewhere in the budget. This item also absorbs the full salaries of the national secretary and office manager, and temporarily includes an appropriation of $2,500 for authorized additions to the staff required by extra duties to be performed for Institute committees and to relieve a congestion of work which develops in some departments at certain seasons of the year; as this expense is incurred later it will be reallocated to the committee or other activity involved. The Institute still maintains the smallest staff per 1,000 members of any of the Founder Societies.

The work of general administration, joint activities, secretarial, and other duties for committees is so broad as to make it difficult to describe the specific services required of the staff within the limitations of space for this article.

Prizes for Papers

On account of the severe effects of the depression upon Institute finances, the board of directors discontinued in the fall of 1932 all cash payments in connection with prizes for papers except those accompanying District Branch paper prizes. Upon the recommendation of the committee on Institute prizes, the board has restored in this year's budget the cash awards of $100 each for the national prize for initial paper and the national prize for Branch paper, as well as the award of $25 for the District prize for initial paper in each district. The budget again provides for the cash award of $25 for the District prize for Branch paper in each District, and for the issuance of certificates of award to the recipients of all other prizes.

Joint Activities

The activities in which the Institute is engaged jointly with other engineering organizations are many and varied and have been so frequently brought to the attention of the membership through the news columns of the monthly journal that it is probably unnecessary to comment on the provisions of the budget for such activities beyond a statement of the amount expended last year and the anticipated expense for the present year. It will be noted that the Institute will contribute toward the support of American Engineering Council the same sum as during the preceding year. With respect to the joint activities which are internal in nature, it will be observed that the appropriation for the support of the Engineering Societies Library has increased in proportion to the higher membership figures as of the present year, and also that the assessment paid to United Engineering Trustees is calculated upon a basis which permits of the desired annual reserve for the depreciation and renewal fund.

Other Appropriations

The remaining items in the budget are self-explanatory in nature, and for the present appropriation year beginning October 1, 1937, involve but a small percentage of the estimated total disbursements.

In closing these comments regarding the proposed expenditure of Institute income, mention should be made that during the year ending September 30, 1937, the board of directors authorized the transfer of $7,500 from general funds to the reserve capital fund, for investment purposes; a similar transfer was authorized at the meeting of the board held on October 28, 1937.

As stated in the budget message of President Harrison, printed elsewhere in this issue, the board of directors has adopted a budget of expenditures for the coming year which appropriates practically all of the estimated income for the corresponding period, and which is substantially in excess of the amount expended last year. It is the expectation of the board, however, that the resultant benefits to the entire membership will fully justify the increased expenditures. Each year the board of directors and finance committee endeavor to adopt a budget that places the proper emphasis on the different phases of Institute activities and which limits the annual expenditures to the total of anticipated yearly income. Membership dues, of course, comprise the principal source of Institute revenue, so that the success of all work planned for in the budget virtually depends upon the prompt collection of dues. It is gratifying to know that this situation is realized by the membership, as evidenced by the fact that the number who are in arrears for dues as of this date is at the lowest figure for several years.

Civil Engineer Honored. Arthur S. Tuttle, former head of the engineering force of the city of New York, N. Y., recently was awarded a certificate of distinguished service. The award was made by Mayor F. H. Laguardia before a large group of engineers and city officials assembled in the chambers of the Board of Estimate and Apportionment, the body that Mr. Tuttle had served as principal assistant engineer, deputy chief engineer, chief engineer, and consulting engineer for over 30 years. In presenting the certificate, the mayor stated that this is an age in which special training is an essential qualification for public office and that Mr. Tuttle's distinguished service to the city stands out as an example of what can be accomplished by obtaining the right men for such service. Mr. Tuttle is a life member of the American Society of Civil Engineers, and has served that society as treasurer, 1919–1920, vice-president, 1932–33: and president, 1935.

More Hydro Power Scheduled for Texas

Preliminary plans incident to the proposed rehabilitation of the Austin Dam located on the Colorado River (of Texas) at Austin contemplate reconstruction of the dam to a height of 63 feet and the construction of a new power house on the west side of the river with an initial hydroelectric generating capacity of some 6,250 kw. Another 6,250 kw installation is planned for the Marshall Ford Dam, some 12 miles upstream from Austin, when that dam shall have been completed and adequate water becomes available.

Under the terms of a proposed agreement between the City of Austin and the Colorado River authority, the Austin Dam rehabilitation will be undertaken by the authority at a cost of about $1,800,000 financed by a PWA loan and grant. The authority is to lease the dam from the city for a 30 year period, furnishing $20,000 worth of free power to the city as rental. The original Austin Dam was finished in 1893, and destroyed by flood in 1900; it was reconstructed in 1911 but never accepted by the city. Through a court decree the city obtained the title in 1934.

Annual Science Exhibition. In concurrence with the annual meetings of several scientific organizations, the annual science exhibit of the American Association for the Advancement of Science is to be held at the Murat Theater, Indianapolis, Ind., December 27–30, 1937. Besides the product displays of various companies the exhibition will feature the recent scientific discoveries of individual investigators and noncommercial research organizations. Among these exhibits will be specimens of equipment used for the measurement of cosmic rays, samples of "heavy" water, and a series of photographs of a recent solar eclipse made by means of new and improved cameras built especially for the purpose.

Poems by Prominent Member. A collection of poems written during the past 25 years by Vladimir Karapetoff (A'03, F'12, Life Member) professor of electrical engineering at Cornell University, has been published under the title of "Rhythmical Tales of Stormy Years." The poems are classified under Lyrical, The Immigrant's Fun, A Crazy Quilt, Religious, Philosophy of Life, and Translations from the Russian. Some of the poems have appeared in various periodicals or been recited at conventions. Copies may be obtained from the Cornell Co-operative Society, Ithaca, N. Y.

Effective Joint Action Among Technical Groups in Cincinnati

By dealing only with the broadest interests of its participating societies, the Technical Scientific Societies Council of Cincinnati, Ohio, has achieved notable success in the promotion of joint activities among technical and scientific groups in that city. The effectiveness of the carefully mapped plan of organization, which brings together in this co-operative effort ten organizations comprising a total of some 1,500 members, is evidenced by the fact that in the two years since the council was organized no serious difficulties have developed, growth and progress alone being noted. With the thought that the experience of the Cincinnati Council might be of assistance elsewhere, L. R. Culver, chairman of the AIEE Cincinnati Section (one of the participating bodies) has prepared the accompanying article which describes not only the final arrangements and results, but also the more difficult preliminary steps that were necessary to assure smooth sailing during the organization period.

The idea of closer contact and mutual support among groups of the Institute type was not new, even locally. There were or had been, in Cincinnati as well as in other large centers, more or less satisfactory local affiliations; it was considered desirable to analyze their difficulties and accomplishments as the preliminary step, before approaching all the groups whose co-operation was desired. Particular attention was given to the reasons for the collapse of previous aggregations of societies. Two elements appeared to be responsible for most of the bickering on the one hand, and lack of interest on the other, with eventual disbandment in either event: (1) too much centralization of authority in one of the participating societies, especially in financial matters; and (2) too few points of contact through which to maintain mutual interest. To forestall these troubles, the organizers in Cincinnati set as their guiding principles that no participating society would suffer any loss of autonomy, that the idea of joint progress and support would be kept actively alive by having several operating committees with definite duties and full representation, and finally that the whole structure would be explicitly subservient to its component parts.

By adhering strictly to the principles laid down, the organizers encountered little or no difficulty in convincing the principal members of the technical community that everything was to be gained by the formation of a technical council among them to promote their joint interests. Included in the program were publishing of notices, sponsoring of joint meetings, reducing of duplication of services, stressing of mutual aims, exchanging of information in overlapping fields of interest and, in general, eliminating sources of conflict while promoting friendly intercourse.

Changing conditions bring changing need no less in the scientific world than elsewhere. With this premise, the organizing committee conducted its work throughout the summer of 1935, laying down a code in which the societies defined their mutual relationships and established their council, restricting their pronouncements to stating their aims and the duties of the several operating committees. By-laws were not framed; in their place the salient actions of the governing committees are preserved for ready reference, as guides but not as mandates for the future. That the organization was carefully mapped out may be realized from the fact that two whole years of operation have disclosed no "sore spots," growth and progress alone being noted. In fact, the code has been revised only once and then only in very minor respects, principally in clarifying the wording.

It may be debatable that the experience of some 1,500 members of ten co-operating societies in Cincinnati may be used elsewhere, perhaps nationally, as a guide to effective group effort. The societies, however, feel that they have dealt only with the broadest interests in establishing their council. They offer the following code for study and, if found suitable, adoption by other technical and scientific groups. No attempt is made to analyze its parts, to point out its restricting clauses or to show how the committees are interrelated; if it requires such interpretation, it fails in its purpose.

Section I—Name

1.01 The co-operative body of the technical societies of Cincinnati shall be known as the Technical and Scientific Societies Council of Cincinnati, hereinafter designated the Council.

Section II—Purpose

2.01 The purpose of the Council shall be to bring together for co-operative effort in rendering more and better service and in furthering scientific and technical activities, the technical societies of the Cincinnati district, which have as their purpose the maintenance of a high professional standing.

2.02 The Council shall have no jurisdiction over the meetings or actions of the constituent societies individually or jointly, its purpose being limited to the co-ordination of the societies' activities.

Section III—Participating Societies

3.01 The following societies are member organizations of the Council:

ACS	American Chemical Society
AIEE	American Institute of Electrical Engineers
ASCE	American Society of Civil Engineers
ASHVE	American Society of Heating and Ventilating Engineers
ASM	American Society for Metals
ASME	American Society of Mechanical Engineers
ECC	Engineers Club of Cincinnati
IES	Illuminating Engineering Society
IRE	Institute of Radio Engineers
SAME	Society of American Military Engineers

3.02 The governing committee of the Council shall be empowered to approve requests of other qualified societies for participation in the Council. This committee shall also be empowered to accept the withdrawal of any society or for just cause to request the withdrawal of any society.

Section IV—Administration

4.01 The administrative affairs of the Council shall be executed by the following committees:

A. Policy committee
B. Program co-ordination committee
C. Publication committee
D. Executive committee

4.02 The policy committee shall be the governing committee of the Council and shall consist of the presiding officers of the participating societies, the chairman of the Council's program co-ordination committee, the chairman of the Council's publication committee, secretary-treasurer of the Council, and two members-at-large.

4.03 The program co-ordination committee shall consist of representatives—one from each society—qualified to act upon their respective program and meeting-arrangement matters. It shall be the duty of this committee so to arrange the programs of the several societies as to reduce conflicts in dates, to encourage joint meetings of two or more societies and generally to promote effective co-ordination of their activities.

4.04 The publication committee shall consist of representatives—one from each society—qualified to act upon publication matters, and the editor of the Council's publication whenever such officer is appointed by the policy committee. It shall be the duty of this committee to prepare and distribute suitable publication material, including the announcements of the meetings of the constituent societies and such other items as the Council may devise.

4.05 The executive committee shall consist of the president of the Council who shall act as chairman, chairman of the program co-ordination committee who shall act as vice-chairman, chairman of the publication committee, secretary-treasurer of the Council, two members of the policy committee selected by that committee, and the junior past-president of the Council. It shall be the duty of this committee to supervise, initiate, and direct in detail the affairs of the Council on behalf, and subject to the approval, of the policy committee. In the event that a member of the executive committee is unable to perform his duties, the policy committee shall appoint a substitute to serve out his term, at the request of the president.

4.06 The chairmen of the several committees and the secretary-treasurer shall serve for a period of one year without re-election. However, each shall serve until his successor has taken office. All positions shall be honorary excepting that of editor.

4.07 Each society shall name, and report to the secretary of the Council, its representatives on the committees before September 1 of each year. Then an organization meeting shall be held by each committee not later than the 20th of September. Each committee meeting shall be called to order by its retiring chairman who first shall present a report of his committee work and make such recommendations as he desires. The retiring chairmen of the program co-ordination and publication committees then shall conduct secret ballot elections of their successors. The new chairmen of these two committees then shall take charge of their meetings and conduct their business, including elections of secretaries if the committees so desire.

4.08 At the organization meeting of the policy committee, after making his report and recommendations, the retiring chairmen shall conduct secret ballot elections of the following officers in the order given:

A. Two members-at-large of the policy committee, to be chosen from the membership in good standing in the constituent societies.

B. President of the Council (who serves as chairman of the policy and executive committees).

C. Secretary-treasurer of the Council (who serves as secretary of the policy and executive committees) to be chosen from the membership in good standing in the constituent societies and not necessarily otherwise a member of the policy committee.

D. One member of the policy committee to serve as member-at-large on the executive committee for a term of two years.

4.09 Each committee shall hold throughout the year such further meetings as may be required, or called by its chairman, but meetings in January and May at least are mandatory.

4.10 The secretary-treasurer of the Council shall perform the customary duties pertaining to his office, but shall be required to submit a financial report at the May meeting of the policy committee. Also, he shall be required to maintain an up-to-date digest of the important actions of the policy and executive committees, including those of earlier years, and to convey this digest to his successor at the organization meeting of the policy committee.

Section V—Finances

5.01 The stated expenses of the Council shall be limited to expense in connection with the publication. They shall be apportioned equitably on

the basis of the services rendered. Each organization's proportionate share of the publication expenses shall be determined on an annual basis.

5.02 Any other expenditure must be approved by the policy committee.

Section VI—Code Revision

6.01 Code revisions involving financial considerations may be enacted or adopted by a three-fourths vote of the policy committee.

6.02 Such other regulations as may be necessary for the conduct of the business of the Council may be enacted or approved by majority vote of those present at any policy committee meeting.

In conclusion, it should be pointed out that the council started with a four-page monthly publication; this is now expanded to 24 pages and it reaches the membership at less cost than the four-page original. This publication, *The Cincinnati Engineer and Scientist*, supports a part-time editor and prints items of common interest in addition to the notices concerning the societies individually. For the present the publication schedule includes ten monthly issues from September through June, and a directory issue released during the summer interval. The 1937 directory includes a dual, alphabetical listing of the entire membership which required a 72-page issue. An innovation recently introduced consists of a gummed strip bound into the center of the publication and divided into sections by perforations; in these sections are printed the emblems of the various societies with associated current meeting dates and places, so that those who wish may detach the sections containing notices of meetings they plan to attend and stick them, in stamp fashion, to their appointment calendars as final reminders.

In addition to publication and other routine duties, the Council has arranged annual joint meetings of all societies at which the average attendance has been over 2,500. These concrete examples of the growth of the movement in Cincinnati are offered as an indication of its merits. It is believed that the general plan can be employed usefully elsewhere.

ASHVE to Hold Meeting. The 44th annual meeting of the American Society of Heating and Ventilating Engineers will be held at New York, N. Y., during the week of January 24, 1938. Joint sessions are planned with the American Society of Refrigerating Engineers and the National Warm Air Heating and Air Conditioning Association. The fifth International Heating and Ventilating Exposition also will be held concurrently at Grand Central Palace.

Current Items From American Engineering Council

A Public Works Department

Definite recommendations for a public works department to be created in the process of government reorganization which is still before Congress are to have consideration during the eighteenth annual meeting of the American Engineering Council's assembly in Washington, D. C., January 13–15, 1938. Special studies by the staff and a comprehensive report of the AEC public works committee regarding the structure of a public works department are to be ready for discussion at that time.

Engineers have advocated a public works department for many years and now that the President's committee on administrative management has also recommended the creation of a public works department, engineers are encouraged to believe that the proposal may be due for serious consideration by this next session of Congress. It is not likely to be without opposition, however, because even the Brookings Institution which made a study for Senator Byrd's committee, failed to support the idea although they did recommend many changes in public works and engineering functions.

One of the major problems is to determine what is public works and to name those bureaus or activities among federal government agencies which should be included in the initial structure of a public works department. The President's committee came to the conclusion that such a department should "advise the President with regard to public works" and that it should be prepared to serve other government agencies as indicated in the following quotation:

> "To design, construct and maintain large-scale public works, which are not incidental to the normal work of other departments, except as their agent on request; to administer federal grants, if any, to state and local governments or other agencies for construction purposes, and to gather information with regard to public works standard throughout the nation."

The complexity of the problem is indicated by the fact that neither one of the more recent studies undertook to name those engineering or public works agencies or functions which should be drawn together into a public works department. The President's committee concluded its suggestion, as follows: "The committee does not assign to the new department particular agencies and bureaus, but leaves this assignment to the Executive when, and if, the Congress enacts a law setting up the general departmental structure."

Conditions with reference to "public works" have changed materially in recent years, and engineers in both public and private life have made many observations and acquired a vast amount of actual experience with public works programs. Recognizing that fact, American Engineering Council is anxious to help to unite engineers in their public responsibility with reference to public works activities undertaken by the federal government, the several states, and local committees. To that end, engineers and engineering organizations are invited to express themselves to the AEC public works committee.

Scientific Research Legislation

The American Engineering Council has appointed a special committee to consider the ramifications of Congressman Randolph's H.R. 7939 for the promotion and co-ordination of scientific research activities as a means for the prevention of unemployment in the future. Congressman Randolph seems to be leading a school of thought which publicly subscribes to the philosophy that an even greater application of technology to industry and business is necessary to insure that expansion of capital outlets which guarantees an increasing volume of employment.

Although the Randolph bill has not come up for action in Congress and is still subject to change, it has aroused much interest among members of the engineering profession. A number of engineers have already filed criticisms and suggestions, and Randolph informs us that he is anxious to have reactions representing all fields of technology. Council has not formulated an official policy with reference to this legislation but the following observations are made available for the convenience of those engineers and engineering organizations who may be concerned about either federal government support or control of research in both pure and applied science.

In essence, Congressman Randolph proposes that instead of having a variety of research projects carried on by government bureaus and special research agencies seeking government funds in an unplanned way for their particular projects, these various efforts be co-ordinated through the establishment of an advisory board made up of representatives of the government, of scientists, and of industry. That approach to the problem has appealed to this organization.

Last year the land-grant colleges introduced a bill proposing the establishment of engineering experiment stations in each state paralleling in general the agricultural experiment station idea. Since the land-grant act is administered through the Agricultural Department, the land-grant colleges believe that any development of such experiment stations should be so administered. Meanwhile the state colleges in 19 states—in some of which there are also land-grant colleges—sought to have this bill modified so that money could be spent at state colleges as well as at land-grant colleges in particular states. In this proposal, the administrative machinery would be located in the Bureau of Standards of the United States Department of Commerce.

A third bill confused the issue further by proposing a plan for government expenditures in the field of business research, this one to be headed in the Department of Commerce. Each of these bills has had the active support in Congress of the particular group of representatives of educational associations, the land-grant colleges having a committee and the state colleges another, the business schools having a third. Mean-

while, of course, certain government bureaus, like the Bureau of Standards and the Bureau of Mines, seek money for fundamental research, and sometimes the regular functions of the government in their research efforts are confused with the proposals outlined above. So far, it has been impossible to secure a meeting of minds between the college groups. Within certain states, there is a feeling of sharp competition, and as a result in earlier years none of the bills have succeeded in passing largely because there has been no meeting of minds in the state by which the Congressman in that state could be induced to take action.

It seems that Congressman Randolph is approaching this matter in a way in which some order might be brought out of this chaos. While the American Engineering council has not committed itself to any detail of the bills, we have been assisting Mr. Randolph in securing all the information he can from all the sources, so he will have before him as complete a picture of the problem as possible before he revises his bill. Our understanding is that Congressman Randolph has the friendly support of the President in his efforts, and this seemed to be an added reason, if anything was to be done in this matter, for working with Mr. Randolph in perfecting his legislation.

Accurate Maps and Public Works

In response to an invitation from the Federal Board of Surveys and Maps, the American Engineering Council, through its committee on surveys and maps, has prepared the following statement to be used by a special committee in an effort to have the "mapping agencies" seek additional appropriations from Congress for the acceleration of "basic mapping" under the Temple Act during the fiscal year ending June 30, 1939.

"American Engineering Council has for many years vigorously supported, in the public interest, the requests of our member engineering organizations that the basic map of the United States be completed at the earliest possible date. As a move in the right direction, American Engineering Council has accepted, in principle, the recommendations made by Secretary Ickes in response to Senate Resolution 281 which requested a program for expediting the topographic mapping of the United States. The recommendations involve a 20-year program and the expenditure of $100,000,000. They would give the Geological Survey $4,000,000 for topographic surveys and maps, and the Coast and Geodetic Survey $1,000,000 for first and second order control surveys in 1938 under such items as the directors of the surveys may designate.

"The committee on surveys and maps of American Engineering Council earnestly hopes that steps will be taken by the Bureau of the Budget and the Congress to appropriate the minimum of $5,000,000 that is called for in this program. They believe that in the interest of public economy, of present immediate need, and of the future conservation of our national resources, this step should be taken.

"Earlier communications from American Engineering Council to the President, to the committees of the House and Senate, and to the various federal and state agencies involved, have pointed out that the fulfilment of original Temple Act passed in February 1925 and supported unanimously by map makers and map users alike, is long overdue. We can think of no more practical contribution to both national economy in a broad sense of planning and national economy in a strict budgetary sense than can be made by the administration and by the Congress at this time. . . .

"The committee, in supporting this first step toward an adequate mapping program, perceives it as only the beginning of a long desired objective and earnestly hopes that every effort be made to carry out the complete plan with additional appropriations annually of such size as will complete a basic map for the United States at the earliest possible date. The committee on surveys and maps of American Engineering Council wishes to record itself as willing to help forward this program in every proper way consistent with the great public desirability for fulfilment of a very real social and economic need for accurate knowledge of both horizontal locations and topography in all sections of this country."

United Engineering Trustees, Inc.

The Joint Engineering Organizations

United Engineering Trustees, Inc., was organized in 1904 as an instrumentality of the Founder Societies, the 4 national societies of civil, mining and metallurgical, mechanical, and electrical engineers. Its purpose is the managing of property and funds in which these societies have joint interests, and it is governed by trustees duly appointed by the societies as their representatives. It maintains 2 departments: (1) the Engineering Societies Library, and (2) The Engineering Foundation.

The corporation (UET, Inc.) manages the Engineering Societies Building and all trust funds placed in the hands of the United Engineering Trustees, Inc.

The Engineering Foundation, founded by the late Ambrose Swasey (HM'28) in 1914, is entrusted with the expenditure of income from endowment and other funds. The ultimate objective of Foundation is stated to be: "for the furtherance of research in science and engineering, or for the advancement in any other manner of the profession of engineering and the good of mankind."

The Engineering Societies Library is a free public engineering library, which, is operated for users at a distance, as well as for those who visit its rooms in the Engineering Societies Building.

In the accompanying articles may be found announcements of the elections recently held by UET and The Engineering Foundation, and abstracts of the annual reports of these organizations and of the Engineering Societies Library.

Election of Officers of United Engineering Trustees, Inc.

Officers to serve the United Engineering Trustees, Inc., for the year 1937–38, were elected at the annual meeting of UET held in the Engineering Societies Building, New York, N. Y., October 28, 1937. D. Robert Yarnall, chief engineer of the Yarnall-Waring Company, manufacturers of power-plant specialties, Philadelphia, Pa., was elected president, and Albert Roberts and H. A. Lardner (A'94, F'13) were chosen vice-presidents. H. R. Woodrow (A'12, F'23) becomes treasurer, and J. P. H. Perry, assistant treasurer. John H. R. Arms, general manager, was re-elected secretary.

The names of all members of the board of trustees of UET for the year 1937–38, including both new and hold-over members, are as follows:

Terms expiring October 1938

J. P. H. Perry	ASCE representative
H. A. Lardner	ASME representative

Terms expiring October 1939

J. P. Hogan	ASCE representative
Albert Roberts	AIME representative
D. Robert Yarnall	ASME representative
H. P. Charlesworth (M'22, F'28, past-president)	AIEE representative

Terms expiring October 1940

O. E. Hovey	ASCE representative
W. D. B. Motter, Jr.	AIME representative
K. H. Condit	ASME representative
H. R. Woodrow (A'12, F'23)	AIEE representative

Terms expiring October 1941

A. L. J. Queneau	AIME representative
F. M. Farmer (A'02, F'13, director)	AIEE representative

Of these, O. E. Hovey, A. L. J. Queneau, and K. H. Condit became reappointed members at the annual meeting, upon presentation of credentials from the Founder Societies. W. D. B. Motter, Jr., fills the unexpired term of H. G. Moulton and H. A. Lardner fills the unexpired term of H. V. Coes. The following committees were appointed:

Finance: Albert Roberts, *chairman;* J. P. Hogan, H. A. Lardner, H. R. Woodrow, D. Robert Yarnall, *ex-officio.*

Real Estate: J. P. H. Perry, *chairman;* A. L. J. Queneau, K. H. Condit, H. P. Charlesworth, D. Robert Yarnall, *ex-officio.*

Engineering Foundation Elects Officers

The annual meeting of The Engineering Foundation was held October 14, 1937, in the Engineering Societies Building, New York, N. Y. F. M. Farmer (A'02, F'13, director) was re-elected chairman, and D. Robert Yarnall was re-elected vice-chairman.

The executive committee is composed of these two, together with George E. Beggs, A. L. Queneau, and W. I. Slichter (A'00, F'12, national treasurer, member for life.)

O. E. Hovey was elected director, and John H. R. Arms was elected secretary.

These officers and the executive committee of The Engineering Foundation are elected by the Foundation board, from among its own members. The Engineering Foundation board is itself elected by the board of trustees of the United Engineering Trustees, Inc. The complete membership of the Engineering Foundation board for the year 1937–38 is as follows:

Name		Term Expires
Four Trustees of U.E.T., Inc.		
A. L. Queneau	AIME	1938
D. Robert Yarnall	ASME	1939
H. P. Charlesworth	AIEE	1939
O. E. Hovey	ASCE	1941
Eight Members Nominated by Founder Societies		
G. D. Barron	AIME	1940
G. E. Beggs	ASCE	1939
F. F. Colcord	AIME	1938
F. M. Farmer	AIEE	1939
W. H. Fulweiler	ASME	1940
Langdon Pearse	ASCE	1938
W. I. Slichter	AIEE	1940
A. E. White	ASME	1939
Three Members-at-Large		
F. M. Becket	AIME	1938
J. V. N. Dorr	AIME	1939
E. R. Fish	ASME	1939

Ex-officio, President, U.E.T., Inc.

D. Robert Yarnall

At the annual meeting members of the research procedure committee were appointed or re-appointed as follows:

D. R. Yarnall, *chairman*, representing The Engineering Foundation.

L. W. Chubb (A'09, F'21) director, Westinghouse Research Laboratories, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., representing AIEE.

F. F. Colcord, representing The Engineering Foundation.

W. H. Fulweiler, Wallingford, Pa., representing The American Society of Mechanical Engineers.

F. O. Scobey, senior irrigating engineer, United States Department of Agriculture, Berkeley, Calif., representing the American Society of Civil Engineers.

Sam Tour, Lucius Pitkin, Inc., New York, N. Y., representing American Institute of Mining and Metallurgical Engineers.

F. M. Farmer (A'02, F'13, director) *ex-officio*.

The personnel of other committees as appointed or re-appointed at this meeting is as follows:

Iron Alloys

G. B. Waterhouse, *chairman and director;* professor of metallurgy, Massachusetts Institute of Technology, Cambridge, Mass., representing American Institute of Mining and Metallurgical Engineers.

Director, National Bureau of Standards, Lyman J. Briggs, represented by Doctor J. G. Thompson, chief of section on chemical metallurgy, National Bureau of Standards, Washington, D. C.

Director, United States Bureau of Mines, J. W. Finch, represented by R. S. Dean, chief engineer, Metallurgical Division, Washington, D. C.

J. T. MacKenzie, metallurgist and chief chemist, American Cast Iron Pipe Company, Birmingham, Ala., representing American Foundrymen's Association.

John Johnston, director of research, United States Steel Corporation, Kearny, N. J., representing American Iron and Steel Institute.

Bradley Stoughton, dean of engineering, Lehigh University, Bethlehem, Pa., representing American Society for Metals.

Jerome Strauss, vice-president, Vanadium Corporation of America, Bridgeville, Pa., representing American Society for Testing Materials.

T. H. Wickenden, metallurgical engineer, International Nickel Company, New York, N. Y., representing The Society of Automotive Engineers.

J. H. Critchett, vice-president, Union Carbide and Carbon Research Laboratories, Inc., New York, N. Y., representing American Electrochemical Society.

Wilfred Sykes (A'09, F'14) assistant to the president, Inland Steel Company, Chicago, Ill., and a director; member-at-large.

F. T. Sisco, *editor*.

Welding Research

C. A. Adams, (A'94, F'13, past-president, member for life) *chairman;* consulting engineer, Edward G. Budd Manufacturing Company, Philadelphia, Pa.

Everett Chapman, president, Lukenweld, Inc., Coatesville, Pa.

J. H. Critchett, vice-president, Union Carbide and Carbon Research Laboratories, Inc., New York, N. Y.

J. J. Crowe, engineer-in-charge of apparatus, research, and development department of Air Reduction Company, Jersey City, N. J.

Table I. Summary of Annual Report of Finance Committee of U.E.T.

Operation of Building

Operating revenue		$ 159,636.82
Less operating expenditures		135,291.79
Net operating income before transfers to reserves		24,345.03
Operating credit previous years		8,151.89
Credit balance September 30, 1937		32,496.92
Transferred to general reserve fund		8,000.00
		24,496.92
Transferred to depreciation and renewal fund		15,000.00
Net balance September 30, 1937		$ 9,496.92

Operation of Library

Maintenance revenue	$43,344.13	
Maintenance expenditures	42,944.15	
Credit balance for year 1937	399.98	
Credit balance from previous year	6,178.69	
Credit balance September 30, 1937		$ 6,578.67
Service Bureau revenue	7,887.08	
Service Bureau expenditures and adjustments	6,597.30	
Credit balance for year 1937	1,289.78	
Credit balance from previous year	4,571.96	
Credit balance September 30, 1937		5,861.74
Total net operating credit balance cumulated to September 30, 1937		$ 12,440.41

Funds and Property

*Combined Fund: Summary of Investments, September 30, 1937

	Legal	Nonlegal	Book Value	Market Value
Funds included:				
Engineering Foundation fund	$494,311.38	$283,226.19	$ 777,537.57	
Edward Dean Adams fund		90,873.03	90,873.03	
Library endowment fund	92,728.21	75,210.25	167,938.46	
Depreciation and renewal fund		352,411.96	352,411.96	
General reserve fund		9,170.68	9,170.68	
Total	$587,039.59	$810,892.11	$1,397,931.70	
Investments: Legal			$ 656,654.72	
Nonlegal			737,309.33	
Total investment, September 30, 1937			1,393,964.05	$1,311,690.72
Cash uninvested			3,967.65	
			$1,397,931.70	

Real estate, cost of—September 30, 1937	$1,987,793.92	
Operating cash	19,280.65	
Accounts receivable, gross	4,196.10	
The Engineering Foundation—unexpended income	18,375.11	
The Engineering Foundation—temporary investments	6,180.00	$ 6,885.00
Alloys of iron research—unexpended income	5,259.75	
The Engineering Foundation custodian fund assets	500.00	
Welding research—unexpended income	6,299.89	
Henry R. Towne engineering fund	50,544.18	$ 36,676.97
Total	$3,496,361.30	

Moneys Held for Special Purposes

Endowment committee (Adams expense fund)	$702.57
Special Library binding fund (W. S. Barstow)	430.33

U.E.T., Inc., Custodian of John Fritz Medal Fund

Securities held September 30, 1937	$3,500.00	$ 3,535.00
Cash on hand September 30, 1937	225.38	

*A group of funds managed as one for convenience and economy in investment transactions.

A. S. Douglass, construction engineer, Detroit Edison Company, Detroit, Mich.

C. L. Eksergian, chief engineer, Budd Wheel Company, Detroit, Mich.

A. J. Ely, mechanical engineer, Standard Oil Development Company, Elizabeth, N. J.

H. M. Hobart (A'94, F'12, member for life) consulting engineer, General Electric Company, Schenectady, N. Y.

D. S. Jacobus (A'03, member for life) advisory engineer, The Babcock and Wilcox Company, New York, N. Y.

G. F. Jenks, colonel, Ordnance Department, United States Army, Washington, D. C.

Jonathan Jones, chief engineer, fabricated steel construction, Bethlehem Steel Company, Bethlehem, Pa.

P. G. Lang, Jr., engineer of bridges, Baltimore and Ohio Railroad, Baltimore, Md.

F. T. Llewellyn, research engineer, United States Steel Corporation, New York, N. Y.

Aubrey Weymouth, vice-president and chief engineer, Post and McCord, Inc., New York, N. Y. (Alternate for Jonathan Jones.)

William Spraragen (A'17, M'26) *secretary*, technical secretary and editor, New York, N. Y.

BARODYNAMIC RESEARCH: ADVISORY COMMITTEE

H. N. Eavenson, mining engineer, Pittsburgh, Pa.

H. G. Moulton, consulting mining engineer, New York, N. Y.

J. W. Finch, director, United States Bureau of Mines, Washington, D. C.

Chairman Farmer is Foundation's representative on the executive committee of National Research Council.

Annual Report Issued by United Engineering Trustees, Inc.

The annual report of United Engineering Trustees, Inc., for the year ending September 30, 1937, has been submitted by G. L. Knight (A'11, F'17), president. The year showed reasonable stability in finances, full occupancy of the Engineering Societies Building, an increasing use of meeting halls, and improvement in the protection of property including resumption of contributions to the depreciation and renewal fund which had by necessity been withheld since 1932. Engineering Societies Building in its thirty-first year of activity remains in good physical condition with a minimum of repairs and maintenance expense. Minor improvements have been made in certain meeting-hall facilities. The American Institute of Chemical Engineers now has made its headquarters in the Engineering Societies Building.

The depreciation and renewal fund additions of $12,000 a year ceased in 1932 in order to lighten the building operating assessment against the societies at a time when the societies' income suffered from lowered volume of membership fees. During the year just closed, $15,000 has been added to the fund, the value of which is shown to be $352,411.96 against a building held at $1,447,793.92. A summary of the report of the U.E.T. finance committee is given in table I.

A new edition of history, charter, and by-laws of the corporation, the first since 1931, was issued just prior to the close of the fiscal year, and gives much of historical and legal interest not only to trustees and members of the Founder Societies, but also to any person who may wish to make a gift or bequest to the corporation or its departments for the advancement of science and engineering.

Annual Report Issued by Engineering Foundation

The annual report of the Engineering Foundation for the year ending September 30, 1937, has been submitted by F. M. Farmer (A'02, F'13, director) chairman of the Foundation board. Chairman Farmer conducted the affairs of the Foundation during the year with the assistance of John H. R. Arms, secretary of United Engineering Trustees, Inc., following the death on March 14, 1937, of Doctor Alfred D. Flinn, secretary and director of the Foundation since 1917.

A summary of the capital fund of the Engineering Foundation and a condensed financial statement follows:

Capital Funds

Endowment, total book value on September 30, 1937	$872,000
E. H. McHenry bequest, in hands of executors until decease of 2 life beneficiaries, appraised at probate of will in 1931, approximately	400,000
Fifth Swasey gift	89,102

The capital funds are held and administered by United Engineering Trustees, Inc. The net income from endowment was $36,596.78 for the fiscal year ended September 30, 1937. The Foundation board has discretion in use of income. For many of the enterprises which the Foundation has aided, large contributions of money, services, and materials have been obtained from others.

Expendable Resources

Balance on October 1, 1936		$17,798.93
Receipts		
Income from endowment	$36,596.78	
Income from minor items	666.44	37,263.22
Total resources		$55,062.15

Disbursements

Research projects	$22,134.28	
Promotion of research and administrative expenses	8,572.76	
Total for furtherance and support of research		30,707.04
Balance on October 1, 1937		$24,355.11

Money "contributions" from organizations and individuals, for specific activities, passed through the Foundation's accounts from its organization to September 30, 1937, totaled $282,851.60.

During the year ending September 30, 1937, the Foundation aided the following activities:

Soil Mechanics and Foundations Division (ASCE, $2,000). The following studies have been completed, or are under way:

(*a*) Settlement of structures. Progress report in the September 1937 ASCE *Proceedings*.

(*b*) Internal earth pressures. Studies have been made principally in New York City and Detroit. Report prepared and now before the publications committee of ASCE.

(*c*) Observed settlement of structures in Egypt. A report is being prepared.

(*d*) Properties of clay-type soils. Many thousands of tests have made made during the year but the program is not yet completed.

(*e*) Lateral stability of sheeting and piles. Some preliminary results have been published.

(*f*) Properties of "quick sands." Investigation just being started.

(*g*) Stability of earth dams subject to seepage. A series of tests is now under way.

(*h*) Problem of sand boils in connection with upward flow of water through soils. A series of tests is under way.

(*i*) Stability of earth banks subject to seepage. Data are being collected.

Hydraulic Researches (ASCE, $1,500). The following projects have been actively pursued during the year:

(*a*) Traveling waves on steep slopes. Studies of waves on a traveling belt through a glass-sided flume; 2 graduate theses have been written.

(*b*) Curves in open channels. Studies including motion pictures have been made with channels set up in Pyralin with the flow around a 180-degree bend.

(*c*) Phenomena of intersecting streams. After preliminary work with small metal flumes, square flumes have been constructed of Pyralin, experiments have been run with branch circuits at various angles, and studies made with water flowing in both directions. A thesis and a report have been prepared on the data obtained to date.

(*d*) Conversion of kinetic to potential energy. Library research and laboratory experiments being simultaneously conducted.

(*e*) Sedimentation at the confluence of rivers. A channel 12 by 24 inches and 65 feet long has been set up with a tributary channel and facilities have been provided for feeding sand to both flumes independently, and for varying the angle of convergence and the slope of the flumes.

Alloys of Iron (AIME, $5,000). This project, a critical compilation of the existing information on the alloys of iron, has been under way for several years. During this year 2 additional monographs were published, the total to date now being 9. Five chapters have been prepared for the tenth volume "The Alloys of Iron and Nickel—Volume I." A refinancing campaign carried on by the director of this project has resulted in subscriptions which with continued support by the Foundation at the present rate, will apparently finance this project to completion.

Barodynamic Researches (AIME, $2,500). Studies have been made of the following:

(*a*) Stress distribution in mine pillars and roofs. These studies are being made with the aid of the centrifugal photoelastic process previously developed in connection with this project.

(*b*) Methods of overcoming rock burst in deep mines.

(*c*) Development of artificial mine supports.

(*d*) The development of apparatus for the determination of pressure in loose materials.

A paper entitled "Modern Methods of Attacking Mining Problems," a direct result of the work on this project, was presented at the February 1937 annual meeting of AIME. It is expected that publication of information resulting from the above activities will be made during the coming year.

Cutting Fluids (ASME, $750). Experimental work completed on monel metal and reported in a paper in the November 1936 issue of ASME *Transactions*. Work being conducted on SAE 2345 steel.

Critical Pressure Steam Boilers (ASME, $850). This project has been under way for some time, the present program being the reaction between steam and metals at high temperatures. Apparatus is being built to test simultaneously 7 different tube materials.

Fluid Meters (ASME, $900). The present experimental program is on flow nozzles, an investigation which has been under way for some time, and is expected to require 3 years to complete. Articles concerning

this study have appeared in several technical journals.

Strength of Gear Teeth (ASME, $700). Twelve test runs have been made on a special surface fatigue testing machine. A series of reports on these tests of surface fatigue being prepared for publication.

Lubrication (ASME, $400). This project under a special research committee has included the compilation of a bibliography on lubrication started some time ago, a study of the problem of viscosity of lubricants under pressure, and investigation of increased viscosity under high pressure in bearing oil films. Two papers have been presented by members of the committee during the year. An extensive survey of lubrication research throughout the United States is being made.

Effect of Temperature on the Properties of Metals (ASME, $500). This extensive project, which has been under way for some years under the direction of a joint committee, the Foundation's contribution to which is a very small amount, was reorganized during the year, but a total of 9 research projects, either new or already under way, were prosecuted during the year.

Stability of Impregnated Paper Insulation (AIEE, $2,000). This project only got under way in 1936 under a supervisory committee designated by AIEE. Some time was spent in overhauling and improving equipment utilized on previous work. Certain preliminary test experiments involving a comparative study of a new procedure and the procedure previously used are nearly completed. Upon completion, the normal program, namely, the determination of the influence of the density and other physical properties of the paper on the electrical properties, the stability, and the life of impregnated paper insulation, will be started and will progress at a steady rate.

Welding Research (AIEE and AWS, $5,939). This project is very active under a large representative committee. The work is being carried on in 3 subdivisions, namely, fundamental research, industrial research, and literature. Each division has a record of important accomplishments during the year. A total of 32 reports comprising 368 printed pages were published during the year. These reports appeared in a supplement of the *Welding Journal*.

Engineers Council for Professional Development ($3,450). The death of General R. I. Rees has interfered with the carrying on of the work at rate contemplated; nevertheless much progress has been made under the chairmanship of Professor Chas. F. Scott (A'92, F'25, HM'29, past-president). The "accrediting schools" project has been highly successful so that during the year the perplexing problem of accrediting engineering education has been definitely solved. The total degree-granting schools that have been inspected to date is 134. Some of the Foundation funds were used for the general overhead expenses of this project but the cost of activity itself is self-liquidating from the fees paid by the schools, which to date have been something like $30,000. A study of the "evaluation of professional qualifications" is still under way. A study has been made of certain "aptitude tests" in 12 institutions which has confirmed previous reports that lack of schooling essential to engineering can be detected by these tests.

Personnel Research Federation ($1,200). A study of "Problems Incident to Engineering Advances" was made during the year and the results published in the *Personnel Journal*. The Federation considers that the extensive responses to these reports fully justify the investigation.

Plastic Flow of Concrete (University of California, $900). This investigation has been under way since 1926, and numerous reports have been issued to date, the most recent being a paper entitled "Plastic Flow and Volume Changes of Concrete" presented at the 1937 annual meeting of the American Society for Testing Materials. These later investigations included the studies to determine

(1) Effect of water-cement ratio and aggregate-cement ratio upon plastic flow.

(2) Effect of fineness and composition of cement upon plastic flow.

(3) Plastic flow of concrete in tension and in compression.

(4) Fiber strains in plain concrete beams under constant sustained bending moment.

(5) Stresses developed in large concrete cylinders under conditions simulating those occurring in mass concrete.

Detailed reports on the foregoing various projects are on file in the Foundation office, and show a large number of specific problems over a wide range, rather than a small number of elaborate problems. Further information on the Foundation and its activities may be obtained from the Foundation office, 29 West 39th Street, New York, N. Y.

Annual Report Issued by Engineering Societies' Library

The annual report of the Engineering Societies' Library, containing information on the use of the library, its finances, and acquisitions, for the year ending September 30, 1937, has been submitted by Doctor Harrison W. Craver, director.

The number of readers was 26,750. In addition, 10,227 nonvisitors were supplied with information and material in various ways: 82 by the loan of 90 books, 112 by special bibliographies, 113 by translations, 2,374 by making 19,535 photocopies, 2,962 by letters, and 4,584 by telephone. Through all these methods, 36,977 persons used the library. In the previous year the library was used by 37,586 persons; 26,784 visitors and 10,812 nonvisitors. The number of users has thus remained practically constant, and the ratio of nonvisitors to visitors (2 to 5) has also remained the same.

Gifts and purchases during the year amounted to 11,003 pieces, of which 6,623 were new to the collection and were added to it. Sixty-seven volumes were added to the loan collection to meet requests from members, and the remaining items were given to other institutions or placed in the duplicate collection for sale or exchange. The sales of duplicates amounted to $431.50. Current issues of 1,416 periodicals were received, and 571 books, worth approximately $2,000, were received for review.

The gifts numbered 9,641 items; among them was that of Colonel W. J. Wilgus who presented his valuable library to the societies' library and the New York Public Library. Under an arrangement for the division of the collection planned by Colonel Wilgus and the directors of the 2 libraries, the societies' library received about 950 volumes and 255 cases of manuscript reports, etc., including all of the collection that dealt with engineering and that was not already on its shelves. A valuable collection of pamphlets by the late Frank J. Sprague (A'87, F'12, past-president) was presented by Mrs. Sprague. Other gifts were received from the *Engineering News Record*, the Perth Amboy Public Library, W. C. Huber, C. T. Hutchinson, Mrs. I. A. Ettlinger, Interborough Rapid Transit Company, Ralph Modjeski, J. L. Nicholson, George Orrok, F. F. Sharpless, and Mygren Werner, Inc.

A continuation of his gift by W. F. Barstow (A'94, F'12, Life Member) has made possible the restoration and rebinding of additional items in the collection of rare books.

On October 1, 1936, the library contained 138,742 volumes, 7,246 maps, and 4,298 manuscript bibliographies. During the year 184 volumes and 40 maps were withdrawn, and 2,734 volumes, 124 maps, and 64 bibliographies were added, bringing the total at the end to 141,292 volumes, 7,330 maps, and 4,362 searches. In addition, 3,701 pamphlets were added to volumes previously counted. The lending collection contained 660 volumes at the end of the year, and approximately 10,000 duplicate volumes and pamphlets were in stock. All new publications have been catalogued when received and made available at once. Cataloging is well abreast of receipts and there is no uncatalogued material except some recent gifts, which are being handled as rapidly as possible.

Substantial progress has been made on the periodical index, which is intended to provide a minutely classified guide to the important periodical literature of engineering. Over 20,000 references were added to the file, which now contains 187,000 references to material published during the past 10 years. The index is becoming increasingly popular with readers, and it is a matter of regret that funds are not available for its extension. More indexers are needed, as the present staff cannot cope with all that is being published.

Early in 1937, a microfilm copy of the library catalogue was made and deposited in a bank vault for safekeeping. From this film, duplicate card catalogues can be made at any time by a simple photographic process. Possession of the film has made possible an important reduction in the amount of insurance carried and so effected a continual annual saving of expense.

The budget for general operations was $46,700. Of this sum, $33,000 was appropriated by the Founder Societies, as follows:

American Society of Civil Engineers	$8,890.90
American Institute of Mining and Metallurgical Engineers	6,921.40
American Society of Mechanical Engineers	8,399.50
American Institute of Electrical Engineers	8,788.20

Expenditures from the appropriation amounted to $42,944.15 of which $8,578.86 was spent for books and other equipment which increased the assets of the library. The service bureau received $7,887.08 and expended $6,581.87.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Rotor Flux Locus Concept of Single-Phase Induction Motor

To the Editor:

In the discussion (*EE, Aug. 1937, p. 1028–30*), of C. T. Button's paper "A Suggested Rotor Flux Locus Concept of Single-Phase Induction-Motor Operation," there was no intention of disagreement and any seeming disagreement is doubtless due to the inability of clearly expressing thoughts in words.

Mr. Button is correct in saying that the condition wherein the rotor flux may be considered as substantially constant along a diameter of the rotor is at or near synchronism. However, this condition was mentioned in the second paragraph and included throughout the comments.

He also states that the "pulsating component in the quadrature rotor axis" is neglected. While this statement is indefinite, it is assumed that it refers to the quadrature flux component. A careful reading of the comments will show that the quadrature flux is accounted for by the double-frequency flux-sustaining currents and the rotation of the rotor. In the assumed case where the rotor is held stationary and the field excited by rectified single-phase current, the factor of field rotation is eliminated and the flux acts only in one fixed direction, so that in this case there is no quadrature space relation, but the flux that is sustained by the double-frequency rotor currents while the primary magnetizing force goes through zero is the quadrature time flux.

The expression "after the rotor flux is once established" was merely intended to exclude the transient conditions as the rotor comes up to speed.

Considering the single-phase motor in the form of a stationary squirrel cage in a field excited by rectified single-phase current is the same method as used in considering a polyphase motor in the form of a squirrel cage in a d-c or constant field. It eliminates the factor of field rotation in both cases.

Mr. Button states that the conditions of coils *A* and *B* are transitory. This is true under slip conditions. However, this assumption of the two coils at right angles was used only in connection with synchronous conditions where they are not transitory. The comments clearly stated that in the practical motor under slip conditions these two sets of currents, the slip or torque currents of slip frequency and the flux sustaining currents of double frequency, less slip, are superimposed, and that the positions of the rotor conductors are constantly shifting from the transformer to the speed condition and vice versa. This action produces the characteristic single-phase rotor current form of one wave of slip frequency with another of double frequency less slip superimposed.

The expression "tendency to keep in synchronism" may be somewhat misleading. However, it does not indicate that the rotor actually attains synchronism, but that there is a tendency in that direction, a well-known characteristic of squirrel-cage motors.

The term "torque" was used in the sense of the torque produced by the electrical reactions between the field and rotor. Unless we eliminate mechanical rotation and reduce to stationary conditions as outlined by holding the rotor stationary and rectifying the single-phase exciting current, there is a negative torque due to friction, windage, etc., but this torque is not pulsating. Pulsating negative torque is only produced above synchronism.

The terms "speed voltage" and "transformer voltage" were used to indicate their source. A speed voltage involves a transformation between electrical and mechanical forces while a transformer voltage involves a transformation between electrical forces.

As Mr. Button states, the reactions under slip conditions are rather complex. It was intended to confine the argument more particularly to synchronous conditions and show how at synchronism, the double-frequency rotor currents maintain the flux approximately constant along a fixed rotor diameter, so that a rotary field is developed by the mechanical rotation of the sustained rotor flux. Other characteristics of the single-phase squirrel-cage motor that are explained by this method were mentioned, but space would not permit taking them up in detail.

Very truly yours,
EDWARD BRETCH (M'19)
President, The Advance Electric Company, St. Louis, Mo.

Personal Items

A. P-T. SAH (A'35, M'36) professor of physics, Tsing Hua University, Peiping, China, recently was appointed president of the National University of Amoy, Amoy, China. Doctor Sah, who formerly served as visiting professor on the electrical engineering faculties of both The Ohio State University and the Massachusetts Institute

A. P-T. SAH

of Technology, was born July 24, 1902, at Foochow, China, and after receiving the degree of bachelor of arts at Stanford University in 1924, enrolled in the electrical engineering school of Worcester Polytechnic Institute, where he received the degree of electrical engineer (1925) and doctor of science (1927). For one year after his graduation in 1927 he was affiliated with the Westinghouse Electric & Manufacturing Company, Pittsburgh, Pa., following which be became chief engineer of the China Radio Corporation, Tientsin. In 1928 he was appointed assistant professor of electrical engineering and physics at Tsing Hua University and in the following year he received his full professorship. In 1936 Doctor Sah returned to the United States as visiting professor of electrical engineering at The Ohio State University and Massachusetts Institute of Technology, and during his stay presented 2 papers on the engineering application of dyadics at the Institute's 1937 winter convention. Since 1935 Doctor Sah has served as a member of the Chinese National Electrotechnical Committee, affiliated with the International Electrotechnical Commission. He is a member of the Chinese Engineering Society, Chinese Science Society, Chinese Physical Society, and the Chinese Institute of Electrical Engineering.

G. M. L. SOMMERMAN (A'31, M'37) research engineer for the American Steel & Wire Company, Worcester, Mass., has been awarded the Alfred Noble Prize for 1937, as reported elsewhere in this issue. The award was made for his paper "Properties of Saturants for Paper-Insulated Cables," which was published in the May 1937 issue of ELECTRICAL ENGINEERING, pages 566–76, and presented at the AIEE 1937 summer

convention, Milwaukee, Wis., June 21–25. Doctor Sommerman was born July 2, 1909, at Baltimore, Md., and received the degrees of bachelor of engineering (1929) and doctor of engineering (1933) at The Johns Hopkins University. Following his graduation in 1929 he became a research assistant at that institution, devoting his attention to investigations sponsored by the former National Electric Light Association, and in the following year enrolled in the graduate school of electrical engineering. In 1931 he became an assistant physicist for the Consolidated Gas, Electric Light, and Power Company of Baltimore, and in 1934 joined the research engineering staff of the American Steel & Wire Company, where he has been in charge of fundamental researches on properties of materials for use in high-voltage cables. Doctor Sommerman is a member of the Institute's committee on research and was a member of the committee on instruments and measurements from 1934 until 1937. He has made many contributions to the technical literature on dielectrics, and has been an active member of the committee on electrical insulation of the division of engineering and industrial research of the National Research Council. He is a member of the American Physical Society, American Association for the Advancement of Science, American Society for Testing Materials, Sigma Xi, and Tau Beta Pi.

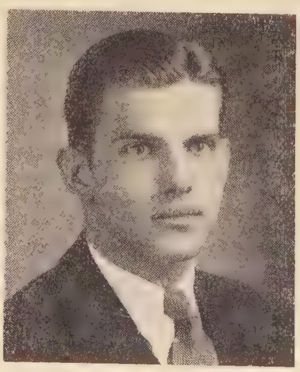
S. A. Tucker (A'28) division engineer, Brooklyn Edison Company, Inc., Brooklyn, N. Y., recently became associate editor of *Power* a periodical published by the McGraw-Hill Publishing Company, New York, N. Y. Mr. Tucker was born October 11, 1905, at New Britain, Conn., and is an electrical engineering graduate of Yale University. Soon after his graduation he became associated with the Brooklyn Edison Company as a cadet engineer, and was associated with that company for more than 10 years.

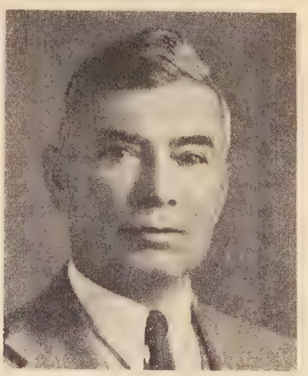
A. J. Allen (M'27) operating vice-president of the Ohio Bell Telephone Company, Cleveland, recently was made president of the Cincinnati and Suburban Bell Telephone Company, Cincinnati, Ohio. Mr. Allen was born April 27, 1881, at Peoria, N. Y., and attended Geneseo State Normal School and Williams College. In 1907 he became associated with the Central District Telegraph Company, Pittsburgh, Pa., as a traffic assistant, later becoming division supervisor of traffic before leaving that company to join the engineering department of the American Telephone and Telegraph Company, New York, N. Y., in 1910. For several years his work with the American Telephone and Telegraph Company was concerned with local operating and engineering problems, but later he became a traffic engineer and in 1929 was made an assistant vice-president of the company. In the following year he was transferred to Cleveland as operating vice-president of the Ohio Bell Telephone Company.

T. H. Hogg (M'31) chief hydraulic enigineer of the Hydro-Electric Power Commission of Ontario, Toronto, has been appointed chairman of the Commission. Mr. Hogg was born April 20, 1884, at Chippawa, Ontario, and received the degrees of bachelor of applied science, civil engineer, and doctor of engineering at Toronto University. In 1908 he became a member of the designing department of the Ontario Power Company, remaining there until 1911, when he became editor of *Canadian Engineer*. His affiliation with the Hydro-Electric Power Commission began in 1913, when he was appointed assistant hydraulic engineer. Doctor Hogg held that position until he was appointed chief hydraulic engineer in 1921. Since 1926 he has served as a consulting engineer for the government of the Dominion of Canada, the Province of Ontario, and for several local power companies.

S. A. Canariis (A'25, M'27) assistant power engineer, Bureau of Water, Department of Public Works of the City of Pittsburgh, Pa., recently was appointed water works electrification engineer for the industrial department of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa. Born in Odense, Denmark, in 1893, Mr. Canariis received his formal technical education at the Polytechnical School of Odense, graduating in 1915. In 1922 he came to the United States, and was employed by several companies in various capacities before being appointed senior engineer of the commercial engineering division of the Duquesne Light Company, Pittsburgh, Pa., in 1926. Mr. Canariis became assistant power engineer for the Bureau of Water of the City of Pittsburgh in 1931.


A. J. ALLEN


G. M. L. SOMMERMAN


T. H. HOGG

R. M. Baker (A'35) research engineer, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., has been appointed to the faculty of the Kansas State College of Agriculture and Applied Science, as an instructor in electrical engineering. Mr. Baker, a native (1903) of College Station, Texas, received the degree of bachelor of science in electrical engineering at the University of Texas in 1926, and the degree of master of science in electrical engineering at the University of Pittsburgh in 1931. Since 1928 he has been employed continuously in the research laboratories of the Westinghouse company, where he has been occupied chiefly in a study of electrical sliding contacts and related problems. During 1932–33 he studied in the Technische Hochschule of Charlottenburg, Germany, and was associated with the Siemens Research Laboratories in Berlin. Mr. Baker has presented several papers before the Institute.

Arthur Simon (A'03, F'13) consulting electrical engineer for the Cutler-Hammer Co., Milwaukee, Wis., has established his own consulting engineering firm, with offices in Milwaukee. Doctor Simon was born in Ebersheim, Germany, May 21, 1881, was educated in the public schools of Germany, and later attended the Technical University of Darmstadt, from which he received a diploma of engineering in 1902. He came to the United States in 1903 when he entered the employ of Cutler-Hammer Company as an electrical engineer. In 1905 he was placed in charge of a-c engineering, and in 1921 was appointed consulting engineer to the company. He served as a member of the Institute's committee on power transmission and distribution, from 1923 until 1925. Doctor Simon will retain his connection with the Cutler-Hammer Company.

J. H. Manning (M'14) president, Stone and Webster Engineering Corporation, New York, N. Y., has retired from active service. Born October 1, 1883 at Fall River, Mass., Mr. Manning was graduated from Worcester Polytechnic Institute with the degree of bachelor of science in civil engineering in 1906 before becoming associated with the consulting engineering firm of Hugh L. Cooper, New York, N. Y., as a draftsman. He remained with that organization until 1910, when he joined the staff of the Stone and Webster Engineering Corporation at Boston, Mass. He was superintendent of construction on many of the Stone and Webster projects throughout the United States, and has been associated with the engineering activities of that organization continuously for 27 years. Mr. Manning is a member of the American Society of Civil Engineers.

S. L. Henderson (A'12, M'34) section engineer for the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., has been promoted to the position of district engineer, with offices at New York, N. Y. A native of Boston, Mass. (1883), Mr. Henderson received the degree of bache-

lor of science in electrical engineering at Massachusetts Institute of Technology in 1910, following which he entered the test course of the Westinghouse Company. In 1913 he was appointed design engineer and successively became division engineer and section engineer. He was a member of the Institute's committee on electrical machinery from 1928 until 1935 (chairman 1932–34) and a member of the technical program committee from 1932 until 1934. At present Mr. Henderson is a member of the sectional committee on rotating machinery of the American Standards Association.

R. C. Mason (A'26) who has been for several years a research engineer for the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., recently has become associated with the Physisch Laboratorium, Utrecht, Netherlands. Mr. Mason is a native (1903) of Bentonville, Arkansas, and an electrical engineering graduate of the University of Arkansas (1924). After graduating from the student training course of the Westinghouse Company, he became an engineer in the materials and process engineering department in 1925, but later was transferred to the research laboratories. Mr. Mason was a member of the electrophysics (now basic sciences) committee from 1933 until 1937 (chairman 1936–37).

W. A. Nichols (A'37) since 1931 an engineer in the special products department of the Northern Electric Company, Ltd. Montreal, Que., Canada, recently became associated with the Canadian Broadcasting Corporation as chief engineer of radio station CBL at Hornby, Ontario. Mr. Nichols, a graduate (1928) of the University of Toronto, formerly was associated with Canadian National Telegraphs, and with the Northern Electric Company, where much of his work was concerned with sound equipment.

J. H. Irwin (A'20) who has been a cable specialty salesman in the Chicago (Ill.) office of the Aluminum Company of America for the last 13 years recently was made manager of the company's Atlanta Ga. office. Mr. Irwin was born December 12, 1892, at Philadelphia, Pa., and was graduated from the University of Pennsylvania in 1915 with the degree of bachelor of science, immediately following which he joined the engineering sales staff of the Aluminum Company of America, with offices at Philadelphia, Pa.

E. W. Conroy (M'32) superintendent of light and power, Puget Sound Power and Light Company, Bremerton, Wash., has been transferred to the central district offices of the company at Seattle, Wash., and has been made assistant to the general superintendent of light and power. Mr. Conroy, a native of Helena, Mont., and an electrical engineering graduate of the University of Washington, has been associated with the Puget Sound Power and Light Company continuously since 1922.

G. W. Thaxton (M'36) formerly division engineering supervisor of the Rural Electrification Administration, Washington, D. C., has become electrical engineer for the Chase Brass and Copper Company, Inc., and the Kennecott Wire and Cable Company, New Orleans, La. Prior to his affiliation with the Rural Electrification Commission, Mr. Thaxton was division engineer of the Tennessee Valley Authority at Tupelo, Miss.

E. L. Moreland (A'11, F'21) partner in the firm of Jackson and Moreland, Boston, Mass., and head of the department of electrical engineering of Massachusetts Institute of Technology, Cambridge, has been appointed to represent the Institute as alternate on the electrical standards committee of the American Standards Association. Professor Moreland is also Institute representative on the standards council of the American Standards Association.

Frederick Bedell (A'91, F'26, past vice-president, member for life) recently retired from his position as professor of physics at Cornell University, Ithaca, N. Y., and will become professor emeritus. Doctor Bedell will continue to do research work at the University and in the R. C. Burt Scientific Laboratories, Pasadena, Calif., where he expects to spend the next few months.

H. S. Dixon (A'35) who has been an assistant engineer, Reclamation District No. 108, Knights Landing, Calif., recently became a member of the electrical engineering staff of Purdue University, Lafayette, Ind. A native (1910) of Woodland, Calif., Mr. Dixon received the degree of bachelor of arts (1931) and the degree of electrical engineer (1935) at Stanford University. He is a member of Tau Beta Pi.

W. M. Leeds (A'32) electrical engineer for the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., recently awarded a B. G. Lamme scholarship by the Westinghouse company, has been granted a year's leave of absence to pursue graduate work at Massachusetts Institute of Technology, following which he will return to the switchgear engineering department of the company.

F. V. Magalhaes (A'07, F'19) executive assistant to the president, Consolidated Edison Company of New York, Inc., New York, N. Y., has been appointed to serve as the Institute's representative on the committee on low-voltage hazards of the National Safety Council, and on the electrical committee of the National Fire Protection Association. Mr. Magalhaes is chairman of the Institute's board of examiners.

J. D. Ross (A'08, F'12) superintendent of lighting, City of Seattle, Wash., and a former member of the United States Securities and Exchange Commission, has been appointed administrator of the Bonneville power project. Mr. Ross has been associated with the city lighting department of Seattle for 30 years, 26 of which have been as superintendent.

E. A. Baldwin (A'07) vice-president and general European manager of the International General Electric Company, Paris, France, recently was made an officer of the Legion of Honor in recognition of his many services to France. Mr. Baldwin has been associated with the General Electric Company since 1896, and has been in the foreign department of the company since 1899.

O. F. Allen (A'10, F'24) consulting engineer, New York, N. Y., recently resigned from his position with the Public Works Administration in New York, to devote his entire time to his consulting engineering practice. He continues as managing director of Martin Motors, Inc., and as secretary and director of American Rezo, Inc.

C. F. Harding (A'06, F'14) vice-president, head of the school of electrical engineering and director of the electrical laboratories of Purdue University, Lafayette, Ind., has been appointed to serve as the Institute's representative on the American Engineering Council assembly for the calendar year 1938.

W. H. Bliss (A'30) formerly an instructor in electrical engineering at the University of Maine, Orono, recently became a communications engineer for RCA Communications, Inc., New York, N. Y., where he is doing experimental work on radio facsimile transmissions.

R. A. Schlegel (A'36) who has been colliery electrician for the Philadelphia and Reading Coal and Iron Company, Mahanoy City, Pa., recently became a service engineer with the Brown Instrument Company Industrial Division of the Minneapolis Honeywell Regulator Company, Philadelphia, Pa.

V. M. Montsinger (A'14, F'29) research engineer, General Electric Company, Pittsfield, Mass., has been appointed to serve as the Institute's representative on the electrical standards committee of the American Standards Association. Mr. Montsinger is chairman of the Institute's committee on standards.

W. M. Bauer (A'29, M'36) since 1929 an instructor in electrical engineering at Northwestern University, Evanston, Ill., now is a part-time assistant in electrical engineering at Harvard University, Cambridge, Mass., where he is enrolled in the graduate school as a candidate for a doctorate degree.

H. M. Witherow (A'28, M'36) designing engineer, General Electric Company, Fort Wayne, Ind., has been transferred to the design department of the General Electric Company, Lynn, Mass. Mr. Witherow is a past chairman (1935–36) of the AIEE Fort Wayne Section.

Macklen Kleiman (A'37) assistant engineer, Thompson Gibb Electric Welding Company, Lynn, Mass., recently became welding engineer for the Lycoming Division of the Aviation Manufacturing Corporation,

Williamsport, Pa. Mr. Kleiman is a member of the American Welding Society.

F. E. Johnson (A'13, F'31, director) dean of the college of engineering, University of Missouri, Columbia, has been appointed to serve as the Institute's representative on the Engineer's Council for Professional Development for the term 1937–40.

F. J. Safford (A'35) who has been an assistant in the electrical engineering department of Columbia University, New York, N. Y., recently was appointed a research assistant in the department of electrical engineering at Massachusetts Institute of Technology, Cambridge.

L. F. Morehouse (A'16, F'20) has been elected to full membership in the British Institution of Electrical Engineers. Doctor Morehouse is technical representative in Europe of the American Telephone and Telegraph Company and of Bell Telephone Laboratories, Inc., with offices in London.

F. M. Farmer (A'02, F'13, director) vice-president and chief engineer of the Electrical Testing Laboratories, New York, N. Y., has been appointed to serve the Institute as representative on the United Engineering Trustees, Inc., for the 4-year term beginning October 1937.

H. A. Lardner (A'94, F'13, member for life) vice-president, The J. G. White Engineering Corporation, New York, N. Y., has been elected a vice-president of United Engineering Trustees, and also a trustee of that agency, representing the American Society of Mechanical Engineers.

Wills Maclachlan (A'08, F'21, past vice-president) consulting electrical engineer, Toronto, Ont., Canada, has been appointed to serve the Institute as representative on the National Fire Waste Council. Mr. Maclachlan is chairman of the Institute's committee on safety.

Douglas Montgomery (A'26) has resigned from the Westinghouse Electric & Manufacturing Company, New York, N. Y., with which company he was a field engineer, to become an electrical draftsman for The Detroit Edison Company, Detroit, Michigan.

J. E. Zipond (A'23) who has been an assistant electrical engineer for the public works branch, United States Treasury Department, Washington, D. C., recently became associated with the Duquesne Light Company, Pittsburgh, Pa., as an electrical engineer.

J. W. Gray (A'36) formerly a teaching fellow in the physics department of the University of Washington, Seattle, now is an instructor in the electrical engineering department of the University of Idaho, Moscow.

G. H. Bliesner (A'35) until recently farm electrification agent for the Puget Sound Power and Light Company, Mount Vernon, Wash., now has become agricultural electrical engineer for the Yam Hill Electric Company, Newburg, Ore.

R. F. Hays, Jr. (A'36) formerly an instructor in the department of physics, Mississippi State College, State College, now is employed as a vapor lamp engineer by the Westinghouse Lamp Division at Bloomfield, N. J.

E. R. Paige (A'35) until recently an electrical engineering instructor at Cornell University, Ithaca, N. Y., has become affiliated with the engineering department of the Niagara Hudson Power Corporation, Buffalo, N. Y.

H. H. Henline (A'19, M'26, national secretary) has been appointed to serve as the Institute's representative on the standards council of the American Standards Association for the 3-year term beginning January 1, 1938.

Roy Wilkins (A'16, F'29) who has been an engineer for the K-P-F Electric Company, San Francisco, Calif., now is associated with the firm of George E. Honn, San Francisco. Mr. Wilkins has been a consulting engineer in that city for several years.

Frank Worel (A'29) who has been chief toll testman of the Michigan Bell Telephone Company, Ann Arbor, has been transferred to the Grand Rapids office of that company as an exchange repairman.

H. L. Collins (A'35) has resigned his position as chief engineer of the Invincible Vacuum Cleaner Manufacturing Co., Dover, Ohio, to become production engineer with the Knapp-Monarch Company, St. Louis, Mo.

Georg Keinath (M'37) director of the laboratories of Siemens and Halske, Berlin, Germany, recently came to the United States to establish consulting engineering offices at New York, N. Y.

K. H. Black (A'37) second lieutenant, U.S. Army Corps of Engineers, Fort Lawton, Seattle, Wash., now is employed in the meter department of the Puget Sound Power and Light Company, Seattle.

K. E. V. Hallar (A'31) formerly assistant operating and maintenance engineer with the Husqvarna Vapenfabriks, Huskvarna, Sweden, now is with the Stone and Webster Engineering Corporation, Boston, Mass.

H. E. Reed (A'32) formerly an electrical operator for the Maine Seaboard Paper Company, Bucksport, now is employed as an electrical tester for the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

C. V. Poling (A'27) formerly an electrical engineer in the Hawthorne works of the Western Electric Company, Inc., Chicago, Ill., has been appointed an assistant electrical engineer for the Tennessee Valley Authority, Knoxville, Tenn.

A. M. Fluke (A'37) who has been a test engineer for the General Electric Company, Schenectady, N. Y., has been transferred to the Bridgeport, Conn., works of that company in the resistance welding engineering department.

R. A. Tyler (A'36) who has been assistant superintendent in the electric department of the Oklahoma Gas and Electric Company, Enid, has been transferred to the Oklahoma City offices of that company as service foreman.

J. R. Eaton (A'27, M'35) until recently an engineer for the Consumer Power Company, Jackson, Mich., has enrolled in the graduate school of electrical engineering at the University of Wisconsin, Madison.

H. D. Larrabee (A'06) operating superintendent of the Connecticut Light and Power Company, Norwich, Conn., has been transferred to the Willimantic offices of that company.

F. B. Weston (A'33) who has been a draftsman for the General Electric Company, Bridgeport, Conn., now is a junior design engineer for M. H. Rhodes, Hartford, Conn.

G. K. Williams (A'34) until recently an electrical engineer at Cornell University, Ithaca, N. Y., now is employed in the inspection development laboratory of the Western Electric Company, Baltimore, Md.

H. R. Woodrow (A'12, F'23, past-director) vice-president of the consolidated Edison Company of New York, Inc., New York, N. Y., has been elected a vice-president of United Engineering Trustees.

Obituary

Robert Calthrop Brown (A'03, member for life) vice-president of the Brazilian Tramway, Light, and Power Company, Barcelona Tramway, Light, and Power Company, Mexican Light and Power Company, Mexico Tramway Company, and Canadian and General Finance Company, Ltd., Toronto, Ont., Canada, died October 30, 1937. Mr. Brown, born June 1, 1866, at Medford, Mass., was graduated from Tufts College with the degree of bachelor of arts in 1888, and received the degree of electrical engineer in 1894. In 1889 he was employed by the Somerville Electric Light Company as lineman, but later in the same year entered the employ of the West End Street Railway Company, Boston, Mass., in its engineering department. In 1890 he was appointed assistant superintendent of electric power in the same company, which position he held for one year before resigning to take charge of the electrical work of the Brooklyn City Railroad, Brooklyn, N. Y., in 1891. In 1894 Mr. Brown became affiliated with the Montreal Street Railway Company as an electrical engineer, and from 1895 to 1898 was employed by the Halifax Tramway, Light, and Power Company as general manager. In 1899 he went to Brazil, where he remained until 1901 as general manager of the Sao Paulo Tramway, Light, and Power Company. From 1902 until 1905 he served as electrical engineer

with the Toronto and the Niagara River Power Company; in 1906 he was appointed managing director of the Mexican Tramways Company, Mexico City, and subsequently held numerous offices in Mexican and South American companies.

Philip Price Barton (A'00, M'01, F'12, member for life) retired electrical engineer, Hartford, Conn., died September 3, 1937. Mr. Barton was born May 5, 1865, at Lock Haven, Pa., and was graduated from Cornell University with the degree of bachelor of philosophy in 1886; he then enrolled in the graduate school and was granted the degree of master of science in 1888, following which he was employed in the electrical department of the Cambria Iron Company, Johnstown, Pa. In the same year he became associated with the Allegheny County Light Company, Pittsburgh, Pa., but remained there only for a brief period before becoming a test engineer for the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., in 1889. Later he was transferred to the Chicago (Ill.) offices of that company as a construction engineer, and remained there until 1891, when he was employed in the office of the special agent of the Brush Electric Company, Pittsburgh, Pa., as engineer and salesman. After serving in a similar capacity in the Pittsburgh offices of the General Electric Company for a brief period, Mr. Barton was appointed assistant electrical superintendent of the Niagara Falls Power Company in 1899. Successively he became superintendent of operation, general manager, vice-president and general manager, serving concurrently as general manager of the Canadian Niagara Power Company, vice-president and general manager of the Niagara Junction Railway Company and the Niagara Development Company, and as director of the Bank of Niagara.

James Aquilla Correll (A'08, M'29) professor of electrical engineering, University of Texas, Austin, died October 30, 1937. Professor Correll was born in Wayne County, Ohio, May 4, 1883, and received the degrees of bachelor of science in mechanical engineering (1903) at Kansas State Agricultural College, bachelor of science in electrical engineering (1907) at Massachusetts Institute of Technology, and master of science in electrical engineering (1925) at the University of Texas. Following his graduation in 1903 he was appointed refrigeration engineer for the Louisiana Purchase Exposition at St. Louis, Mo., and following the close of the exposition, became assistant engineer for the Zeigler Coal Company, Zeigler, Ill. In 1907 he was apopinted to the faculty of the University of Texas as an instructor in electrical engineering, later becoming adjunct professor (1915), associate professor (1918), and professor of electrical engineering (1927). During the World War he was head of the engine division of the United States Government school of military aeronautics at the University of Texas. Professor Correll was co-author of a textbook on a-c circuits, and was a member of the Society for the Promotion of Engineering Education and the former National Electric Light Association.

Albert Benton Junkins (M'24) contracting electrical engineer, Baltimore, Md., died in July 1937, according to word just received at Institute headquarters. Mr. Junkins was born in Baltimore February 12, 1894, attended Baltimore City College, and received the degree of bachelor of science in electrical engineering at The Johns Hopkins University in 1917. Following his graduation he became assistant to the power plant engineer of the Chesapeake and Potomac Telephone Company, Baltimore, but in the following year received a commission in the communication branch of the United States Army Air Corps, serving as an instructor in radio and telephone communication. In 1919 he returned to his former position with the Chesapeake and Potomac Telephone Co., but remained for only one year before becoming electrical engineer for the Union Ship Building Company, Baltimore. In 1921 Mr. Junkins became affiliated with Stone and Webster, Inc., as assistant to the electrical superintendent on the construction of the American Sugar Refinery, Baltimore, and upon completion of that project became electrical engineer for the newly organized company. After serving briefly as a construction engineer for the Electromechanical Company, Baltimore, he established his own electrical contracting business, and pursued it without interruption for more than 10 years.

Membership

Recommended for Transfer

The board of examiners at its meeting on November 18, 1937, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Case, H. M., chief engineer, Long Island Lighting Company, New York, N. Y.
Hunt, L. F., protection engineer, Southern California Edison Company, Ltd., Los Angeles, Calif.
McKearin, J. P., chief engineer, Western Massachusetts Companies, Springfield, Mass.
Wooldridge, William J., manager, electric sheet sales, Allegheny Steel Company, Brackenridge, Pa.

4 to Grade of Fellow

To Grade of Member

Baker, T. S., chief engineer, communications division, Hearst Radio, Inc., New York, N. Y.
Bellows, K. F., division engineer, Consolidated Edison Company of New York, Inc., New York, N. Y.
Blakeslee, T. M., electrical engineer, Bureau of Power and Light, Los Angeles, Calif.
Burke, J. H., electrical engineer, The Scranton Electric Company, Scranton, Pa.
Craton, F. H., commercial engineer, General Electric Company, Erie, Pa.
Hapgood, K. E., assistant engineer of design and construction, Tennessee Valley Authority, Chattanooga, Tenn.
Hough, E. L., electrical engineer, Union Electric Company, St. Louis, Mo.
Keene, C. L., supervising engineer, Ocean Accident and Guarantee Corporation, New York, N. Y.
Leiby, C. W., editor, *Electric Light and Power*, Chicago, Ill.
Love, N. R., chief engineer, Denver Tramway Corporation, Denver, Colo.
McLean, C., assistant engineer, Northwestern Electric Company, Portland, Ore.
Scheering, W. S., substation engineer, Western Mass. Companies, Springfield, Mass.
Schlup, E. G., electrical engineer, The American Rolling Mill Co., Middletown, Ohio.

13 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before December 31, 1937, or February 28, 1938, if the applicant resides outside of the United States or Canada.

Anderson, J. W., Metropolitan Water District of Southern California, Los Angeles, Calif.
Bagnall, V. B. (Member) American Telegraph and Telephone Company, New York, N. Y.
Bain, J. R., Dominion Sound Equipments, Ltd., Vancouver, B. C., Canada.
Baker, B. P., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Bloodworth, E. W., Wilson Dam, Ala.
Bloxam, E. L., Duke Power Company, Salisbury, N. C.
Borland, E. E., Smith Milligan Electric Company, Tulsa, Okla.
Breon, K. H., Pennsylvania Power & Light Company, Williamsport, Pa.
Brown, F. H., Copperweld Steel Company, New York, N. Y.
Browne, A. A., Westinghouse Electric & Manufacturing Company, Portland, Ore.
Bulliet, L. J., W. F., and John Barnes Company, Rockford, Ill.
Cain, D. E., General Electric Company, St. Louis, Mo.
Caplan, R. S., Gulf Refining Company, Houston, Texas.
Cartmell, A. W., Municipal Light and Power Department, City of Pasadena, Calif.
Clayton, M. B., Tennessee Valley Authority, Wilson Dam, Ala.
Colby, B. H., General Electric Company, Pittsfield, Mass.
Cook, V. M., Consolidated Edison Company of New York, Inc., New York, N. Y.
Davenport, H. H., Southwestern Bell Telephone, Company, San Antonio, Texas.
Dillon, H. W., Southern Pacific Lines, Houston, Texas.
Doumaux, A. R., General Electric Company, New York, N. Y.
Elliott, R. M., Pacific Telephone and Telegraph Company, San Francisco, Calif.
Evans, K., Canadian Westinghouse Company, Hamilton, Ont., Canada.
Fay, F. H. (Member) American Telephone and Telegraph Company, New York, N. Y.
Fisher, H. J., Bell Telephone Laboratories, Incorporated, New York, N. Y.
Galassini, J. P., Commonwealth Edison Company, Chicago, Ill.
Garman, G. W., General Electric Company, Schenectady, N. Y.
Glenny, W. W., Reliance Electric & Engineering Company, Cleveland, Ohio.
Gower, A. G., Jr., (Member) Westinghouse Electric and Manufacturing Company, Boston, Mass.
Grandi, L. L., Agriculture and Mining College of Texas, College Station.
Hannah, E. I., Maydwell & Hartzell, Inc., Los Angeles, Calif.
Harker, D. C., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Hebbard, R. E., Interborough Rapid Transit Company, New York, N. Y.
Hawekotte, R. M., Bell Telephone Laboratories Incorporated, New York, N. Y.
Hochstetter, P. E., United American Bosch Corporation, Springfield, Mass.
Huffstutter, J. W., Westinghouse Electric & Manufacturing Company, Sharon, Pa.
Hull, R. (Member) Delco-Remy Corporation, Anderson, Ind.
Jimenez-Michelena, L. G., Massachusetts Institute of Technology, Cambridge.
Johnson, J. S., Stone and Webster Engineering Corporation, Hartford, Conn.
Kerr, T. B., Quincy Electric Light and Power Company, Quincy, Mass.
Klingensmith, J. A., Electric Storage Battery Company, Washington, D. C.
Kotchevar, J. F., Janette Manufacturing Company, Chicago, Ill.
Kurth, H. L. R. (Member) Boston Edison Company, Boston, Mass.
Lachicotte, F. W. (Member) Duke Power Company, Charlotte, N. C.
Lachicotte, F. W., Jr., Carolina Power and Light Company, Canton, N. C.
Leatherman, L. A. (Member) Bell Telephone Laboratories, Incorporated, New York, N. Y.
Lovoi, F. J., Houston Light and Power Company, Houston, Texas.
Luenberger, F. O., U. S. Electrical Motors, Inc., Los Angeles, Calif.
MacDonald, M. W., 622 West 113 Street, New York, N. Y.
Marshall, R. T., Houston Lighting and Power Company, Houston, Texas.
Martin, E. L., Tennessee Valley Authority, Chattanooga, Tenn.
McKinley, W. W., Commonwealth and Southern Corporation, Jackson, Mich.
Melcher, J. C., Leeds & Northrup Company, Philadelphia, Boston, Mass.

Miller, A. R., Union Metal Manufacturing Company, Canton, Ohio.
Minneci, S., General Electric Company, Pittsfield, Mass.
Monfort, C. E., Jr., Union Electric Company of Missouri, St. Louis.
Morton, L. W., General Electric Company, Schenectady, N. Y.
Murphy, W. J., Consolidated Edison Company of New York, Inc., New York, N. Y.
Naylor, H. E. Jr., Tennessee Valley Authority, Wilson Dam, Ala.
Nelson, C. B. (Member) Nelson Electric Supply Company, Nelson Electric Manufacturing Company, Tulsa, Okla.
Nelson, S. H., Southern New England Telephone Company, New Haven, Conn.
Pakala, W. E., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Palermo, A. J., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Palmer, R. J., Virginia Public Service Company, Alexandria, Va.
Porter, W. J., Canadian Westinghouse Company, Hamilton, Ont., Canada.
Ross, A., Moloney Electric Company, St. Louis, Mo.
Ross, W. E. (Member) Canadian General Electric Company, Ltd., Toronto, Ont., Canada.
Russ, J. C., General Electric Company, Pittsfield, Mass.
Shower, E. G., Bell Telephone Laboratories, Incorporated, New York, N. Y.
Silbermann, E. F., United States Navy, New York, N. Y.
Sloan, K. H., United States Navy, New York, N. Y.
Smith, R. E. (Member) Public Service Company of Northern Illinois, Evanston.
Southall, C. S. (Member) Phoenix Engineering Corporation, New York, N. Y.
Spiller, P., Consolidated Edison Company of New York, Inc., New York, N. Y.
Stewart, G. S. (Member) Canadian General Electric Company, Toronto, Ont., Canada.
Thomas, S. H., General Electric Company, New York, N. Y.
Thring, R. G. (Member) Capital Transit Company, Washington, D. C.
Ulmer, L. S., 849 Harrison Avenue, Schenectady, N. Y.
Volle, G. H., Union Electric Company, Monsanto, Ill.
Wane, D., Canada Wire and Cable Company, Ltd., Leaside, Ont., Canada.
Weiser, L. G., Westinghouse Electric and Manufacturing Company, Louisville, Ky.
Whitner, R. L. (Member) Roller-Smith Company, Bethlehem, Pa.
Wilkoff, H. M. (Member) American Steel & Wire Company, Worcester, Mass.
Williamson, R. L., Aluminum Company of America, Atlanta, Ga.
Wright, F. T., Underwriters' Laboratories, Inc., New York, N. Y.
Zurcher, L. A., Case School of Applied Science, Cleveland, Ohio.

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Foreign

Anand, L. S., City and Guild Laboratories, London, England.
Bhargava, M. L., 35 Hussain Ganj, Lucknow, India.
Caparro's, J. R. R., Public Service Commission, San Juan, Porto Rico.
MacLean, L. R., Bolivian Power Company, Oruro, Bolivia.
Maissi, E., 39, rue Dulong, Paris 17e, France.
Megwinoff, I., Power Electric Company, San Juan, Puerto Rico.
Rama Rao Naidu, D. V., Madanapalle Electric Supply Corporation, Ltd., Madanapalle, South India.
Wear, R. H. (Member) Messrs. Blackstone and Company, Ltd., Sydney, Australia.

8 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Boissonnault, F. L., 928 W. 8th Place, Los Angeles, Calif.
Charlton, H. C., 4827 Wilson Avenue, Montreal, Que., Canada.
Cooper, Peter G., 50 Stanton St., Schuylkill Haven, Pa.
Dadashev, Musa, 32 Zamkovaja, Ulitsa, Baku, U.S.S.R.
Fassett, Frank C., 100 Seward Ave., Detroit, Mich.
Gregory, G. A., 1217 Jefferson Street, Olympia, Wash.
Hall, John R., 1464 S. 74th St., West Allis, Wis.
Herr, Melvin D., South 228 Lincoln St., Spokane, Wash.
Kirk, W. C., 216 E. 22nd St., Owensboro, Ky.
Koziol, Roman Joseph, 174 Farmington Ave., Hartford, Conn.
Macomber, George S., Federal Power Commission, Washington, D. C.
McLean, Lee Vance, 1926 North Blvd., Baton Rouge, La.
Rizk, Kaleel S., Co. 418, C.C.C., Olustee, Fla.
Roberts, William N., 4175 Springle, Detroit, Mich.
Tribble, William Harry, 303 Park Place, Brooklyn, N. Y.

15 Addresses Wanted

Engineering Literature

Among the new books received at the Engineering Societies Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

ENGINEERING MECHANICS, DYNAMICS. By S. Timoshenko and D. H. Young. New York and London, McGraw-Hill Book Company, 1937. 323 pages, illustrated, 9 by 6 inches, cloth, $2.75. An elementary textbook on dynamics intended to give the student a thorough grounding in fundamentals. Contains discussions of 3 phases of the subject not usually contained in elementary books: vibration, elliptic harmonic motion, and relative motion.

ENGINEERING PROBLEMS MANUAL. By F. C. Dana and E. H. Willmarth. Third edition. New York and London, McGraw-Hill Book Company, 1937. 313 pages, illustrated, 8 by 5 inches, cloth, $2.25. A textbook for courses in engineering problems with the object of training the engineering student in good habits of work and study. The first 7 chapters furnish a ground work for this training; chapter 8 presents some 300 review problems; and chapter 9 contains miscellaneous tables.

MECHANICS and HEAT. (Physics for Technical Students). By W. B. Anderson. Third edition. New York and London, McGraw-Hill Book Company, 1937. 378 pages, illustrated, 9 by 6 inches, cloth, $2.50. This first volume of a set covers only mechanics and heat; sound, light, electricity, and magnetism are covered in a second volume. Intended as an elementary textbook.

TEXTBOOK of PHYSICS. By L. B. Spinney. Fifth edition. New York, Macmillan Company, 1937. 721 pages, illustrated, 9 by 6 inches, cloth $3.75. A textbook for university and college students emphasizing the practical applications of physics and illustrates the laws by reference to familiar phenomena.

THERMODYNAMICS. By H. A. Everett. New York, D. Van Nostrand Company, 1937. 430 pages, illustrated, 9 by 6 inches, cloth, $3.75. A textbook for a college course. Covers fundamentals and discusses various phases in the light of modern developments.

WIRELESS SERVICING MANUAL. By W. T. Cocking. Third revised edition. London, *Wireless World*, Iliffe & Sons, Ltd., 1937. 241 pages, illustrated, 8 by 5 inches, cloth, 5s. Covers the principles and practice of the repair and adjustment of wireless receivers. Deals in detail with methods of fault finding and describes the use of test apparatus.

THÉORIE et PRATIQUE des CIRCUITS FONDAMENTAUX de la T.S.F. By J. Quinet. Paris, Dunod, 1937. 431 pages, illustrated, 10 by 7 inches, paper, 120 frs. (140 frs., bound). An elementary study of the use of the calculus of imaginaries in the field of wireless telephony. Divided into 3 parts: the first deals with applications of the method to radio; the second shows its application to electricity; the third, application to the theory and construction of fundamental circuits in wireless telephony.

STROM- und SPANNUNGSWANDLER. By M. Walter. Munich and Berlin, R. Oldenbourg, 1937. 159 pages, illustrated, linen, 8.80 rm. Describes current and voltage transformers for switching installations. Covers current and voltage transformers as to method of operation, construction, safety precautions, connections, selection, and test procedures.

SCIENCE of SEEING. By M. Luckiesh and F. K. Moss. New York, D. Van Nostrand Company, 1937. 548 pages, illustrated, 9 by 6 inches, cloth, $6.00. A treatment of aspects not primarily considered in the various sciences with which seeing is connected. Discussions deal largely with controllable factors—physiological, typographical, illuminative.

SAGA of the SEAS. By P. B. McDonald. New York, Wilson-Erickson, 1937. 288 pages, illustrated 10 by 6 inches, cloth, $3.00. A biography of Cyrus W. Field, of which the greater part is devoted to his greatest achievement, the laying of the first Atlantic cable. Illustrated with contemporary prints and portraits.

RICHARD COCKBURN MACLAURIN. By H. G. Pearson. New York, Macmillan Company, 1937. 302 pages, illustrated, 9 by 6 inches, cloth, $3.00. A biography of the president of the Massachusetts Institute of Technology, 1909–1920. Chiefly concerned with his work in that capacity.

RADIO ENGINEERING. By F. E. Terman. Second edition. New York and London, McGraw-Hill Book Company, 1937. 813 pages illustrated, 9 by 6 inches, cloth, $5.50. Revised edition of a comprehensive engineering treatment of the more important vacuum-tube and radio phenomena.

PSYCHOLOGY of SELECTING EMPLOYEES. By D. A. Laird. Third edition. New York and London, McGraw-Hill Book Co., 1937. 316 pages, illustrated, 9 by 6 inches, cloth, $4.00. A practical treatment of the fundamental considerations in selecting men. Discusses psychological means and methods of selecting employees, and shows the employer how to find efficient employees in his own establishment, as well as in his employment office.

PREPARATION for SEEKING EMPLOYMENT. By H. L. Davis. New York, John Wiley & Sons, 1937. 39 pages, tables, 8 by 6 inches, paper, $0.25. A pamphlet for the guidance of those who seek employment for themselves or others.

PHYSICS for STUDENTS of APPLIED SCIENCE. By J. E. Shrader. New York and London, McGraw-Hill Book Company, 1937. 638 pages, illustrated, 9 by 6 inches, cloth, $4.00. Presents fundamentals necessary to give the technical student a working knowledge of physics.

MODERN THEORIES of INTEGRATION. By H. Kestelman. Oxford, England, Clarendon Press; New York, Oxford University Press, 1937. 252 pages, tables, 10 by 7 inches, cloth, $5.50. Concerned primarily with the theory of Lebesgue integration as simplified by C. Carathéodory. Designed as to be intelligible to one having a knowledge of elementary analysis. Includes discussion of Riemann integration, extensions of the Lebesgue integral, and Fourier series.

MANUAL of MATHEMATICS and MECHANICS. By G. R. Clements and L. T. Wilson. New York and London, McGraw-Hill Book Company, 1937. 266 pages, illustrated, 9 by 6 inches, leather $3.75. Contains facts and formulas useful in courses in mathematics and mechanics, also for general reference work.

LABOR'S SEARCH for MORE. By M. Keir. New York, Ronald Press Company, 1937. 527 pages, 9 by 6 inches, cloth, $3.50. Endeavors to present a record of the struggles, in recent times, of ordinary persons to improve their lot. Intended to furnish an insight as to why workers have been and are seeking more security, more income, more leisure. Strikes, trials, political campaigns, and mechanization are considered along with general economic data.

Engineering Societies Library
29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a co-operative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

1937 Index—Electrical Engineering and Transactions

This multientry annual reference index covers comprehensively the entire text content of the 12 issues of ELECTRICAL ENGINEERING published during 1937 and the identical content of the 1937 AIEE TRANSACTIONS, volume 56; the index covers also a supplement of 28 pages published in the TRANSACTIONS, which contains the following two papers not published in ELECTRICAL ENGINEERING:

1. FUNDAMENTAL CONCEPTS OF SYNCHRONOUS MACHINE REACTANCES, by B. R. Prentice (pages 1–21 of supplement).

2. PER-UNIT QUANTITIES, by Irven Travis (pages 22–8 of supplement).

A special effort has been made to provide effective correlation between references to technical papers and all published discussions of those papers. Discussions of many technical papers published during the latter part of 1936 were published in the early part of 1937, and hence appear in this current index. Likewise, many discussions of the later 1937 papers will be published early in 1938, and consequently will not be found among the references contained in this current index.

For convenience in use, this index is subdivided into the following general sections:

1. Technical subjects.
2. Authors, including the writers of discussions.
3. News items pertaining to Institute activities.
4. News items of a general nature.
5. Biographical (personal and obituary) items.

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MEETINGS, DISTRICT EXECUTIVE COMMITTEE

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Division V—Biographical Index

Includes All Personal and Obituary Items.

NOTE—An asterisk (*) before a page number denotes publication of individual's picture on that page.

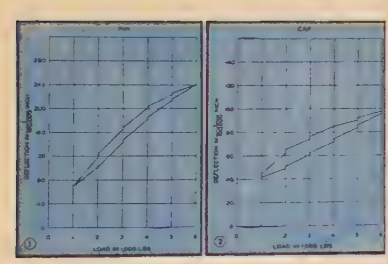
B

All Out of Shape!

IT'S part of her job--to get into "fearful and wonderful" positions--and it requires the utmost in flexibility. Suspension insulators, too, get out of shape in the performance of their job, and must possess flexibility to have long life.

Mechanical and thermal loads stretch the metal parts of insulators, a factor which would be serious if the cap and pin were not able to take this stretching without damage and return to normal position quickly and surely upon release of load.

O-B suspension insulators are designed to provide this quick return to normal. Extensive checks on their behavior under varying loads and temperatures prove the soundness of the designs. And now O-B steps forward and *guarantees* Insured Return in its suspension insulators.



Measurements of insulator movement and return. These graphs plot the measurements of the cap and pin movement of an O-B insulator under successive increases up to the ordinary maximum working load. Notice how the insulator parts return to their original positions when load is released. This is Insured Return!

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The Mark that means—
Insured Return in Suspension Insulators

You'd turn off

Comer Turley, mechanical superintendent, Pepperell Mfg. Co., Lindale, Georgia

It paid Pepperell to replace antiquated, deficient electric wiring

With approximately 2,000 motors in the plant of Pepperell Mfg. Co. at Lindale, Ga., burn-outs have been so reduced by installing over-size feeders that in five years there has not been a single case of rewinding on a spinning-frame, loom, or card-room motor because of overload. "The practice of installing over-size feeders is good insurance and saves on power bills," says Comer Turley, Mechanical Superintendent, "yet it involves only a small additional investment since labor cost is the same. We design feed lines for a load from 50% to 100% greater than immediate requirements."

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a dripping faucet

—why not stop invisible electrical leaks?

Neglecting electrical circuits costs factory owners thousands in breakdowns . . . high power bills

YOU can *see* a faucet dripping. But an overloaded electric circuit may be wasting money in the form of heat losses without your ever knowing it. Only the treasurer, wondering why bills are so high, suspects that something must be wrong.

Heat losses are but one way in which dollars fly out the window needlessly when electrical circuits are neglected. Frequent breakdowns are another. Men and machines stand around idle. Or, voltage drops reduce machine output. Lumped together, the damages the industrial plant suffers from antiquated, deficient wiring are often enormous. And authorities estimate that *nine out of ten industrial plants today are being penalized because of obsolete electric wiring!*

Safeguard your plant

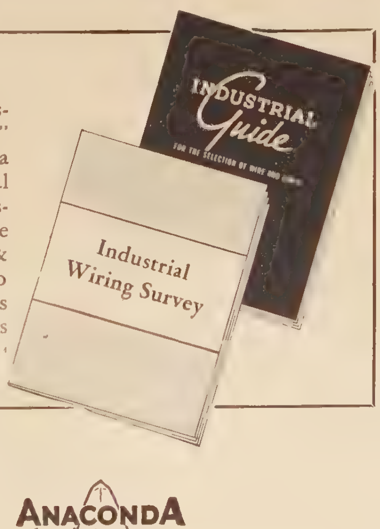
A wiring survey will cost you nothing and may save you thousands of dollars. We offer here a complete plan for such a survey. The books shown at right give you everything you need to initiate a check-up of your plant's circuits. New, informative, they are being used by hundreds of manufacturers. Send for them today.

If you have a specific problem in mind, consult our Engineering Department. We will cooperate without obligation. Why not take advantage of the many important improvements in cable design pioneered by Anaconda Wire & Cable Co.? Let us tell you about them.

Outstanding characteristics of this Anaconda cable are: 1. Its remarkable stability. This has been demonstrated by tests as well as by use in the field. 2. The compound is highly resistant to moisture, acids and alkalies. 3. Low susceptibility to combustion and explosion. 4. Its heat-resisting characteristics permit large emergency overloads.

Write for data on Duracode

FREE! The "Industrial Wiring Survey" tells how to make a check-up of electrical circuits. The "Industrial Guide for the Selection of Wire & Cable" tells how to correct conditions found. Both books will be sent free. 3754



Cable Company

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from mine to consumer

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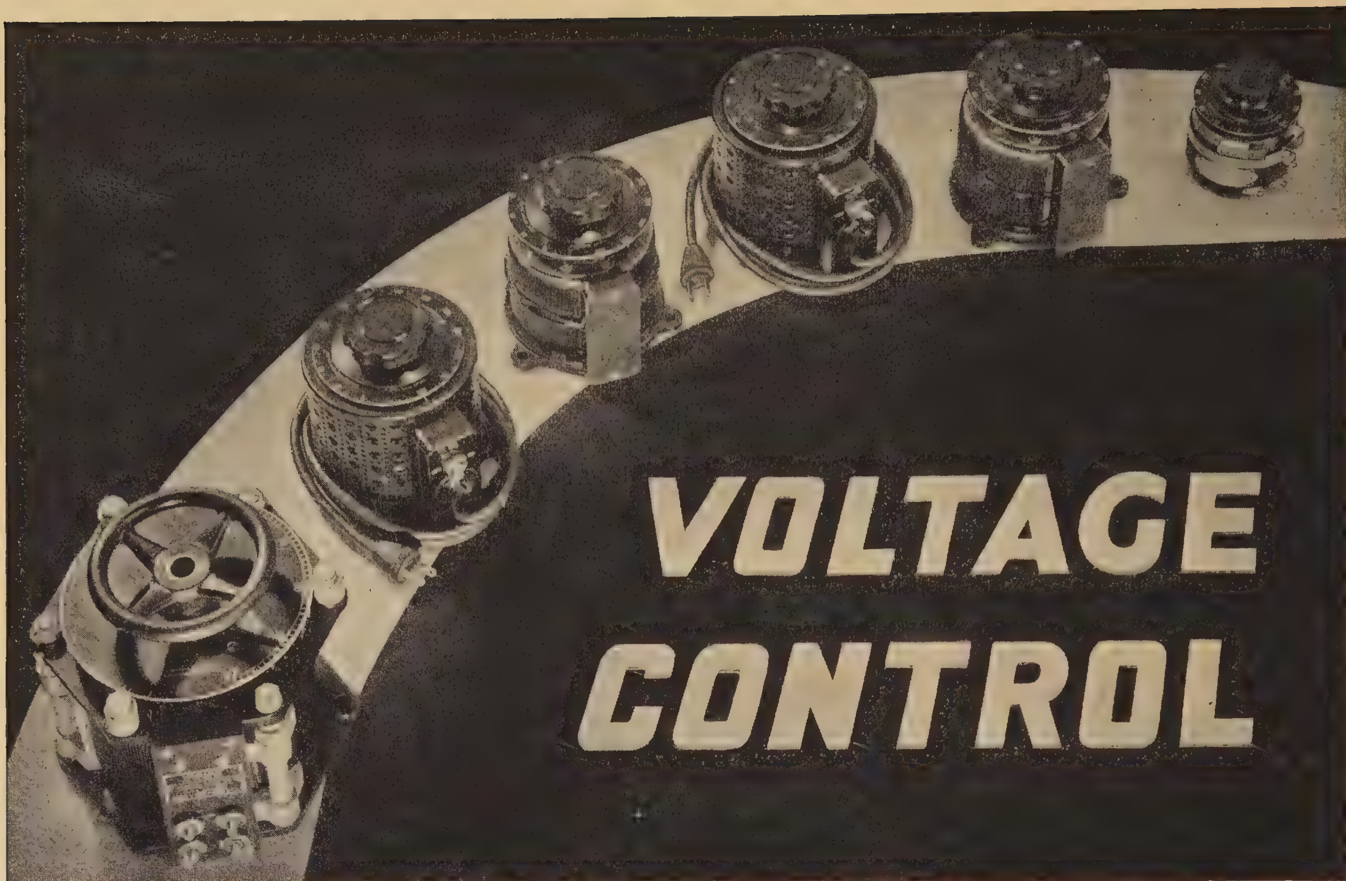

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Thousands of enthusiastic users testify to the general utility of the VARIAC* *continuously adjustable* autotransformer for use in hundreds of different applications where exactly the right voltage is required on *any* a-c operated device.

The VARIAC is the original continuously adjustable manual voltage control with these exclusive features found in no resistive type of control unit.

- **EXCELLENT REGULATION**—Output voltages are independent of load up to the full load rating of the VARIAC.
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- **SMOOTH CONTROL**—The VARIAC may be set to *any* predetermined output voltage with absolutely smooth and stepless variation.
- **HIGH EFFICIENCY**—Exceptionally low losses at both no load and at full power.
- **SMALL SIZE**—VARIACS are much smaller than any other voltage control of equal power rating.
- **LINEAR OUTPUT VOLTAGE**—Output voltages are continuously adjustable from *zero* by means of a 320 degree rotation of the control knob.
- **CALIBRATED DIALS**—VARIACS are supplied with dials which read directly in output voltage or in output voltage as a percentage of line voltage.
- **SMALL TEMPERATURE RISE**—Less than 50 degrees C. for *continuous duty*.
- **ADVANCED MECHANICAL DESIGN**—Rugged construction—no delicate parts—two or more units may be ganged on the same shaft to control several circuits simultaneously.

VARIACS are stocked in fourteen models with power ratings from 170 watts to 2 kw; special units to meet the exact requirements of individual users may be obtained promptly and economically in quantity. Prices on the stock models range between $10.00 and $40.00.

** Trade name VARIAC is registered at U. S. Patent Office. VARIACS are patented under U. S. Patent 2,009,013 issued to General Radio Company.*

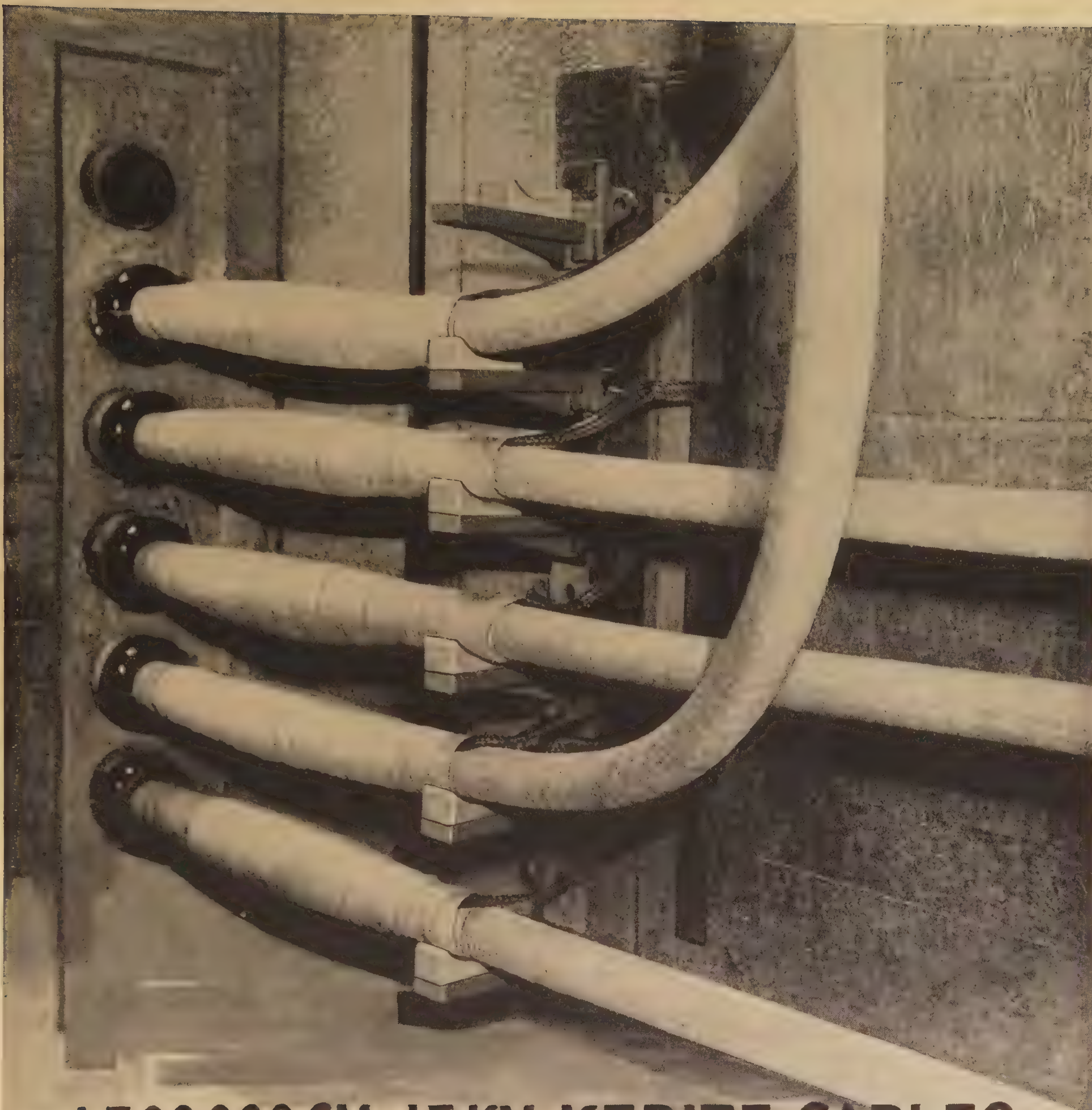
Write for Bulletin 208 for Complete Data

GENERAL RADIO COMPANY

Cambridge, Massachusetts

BRANCHES: New York Los Angeles San Francisco

MANUFACTURERS OF RADIO AND ELECTRICAL LABORATORY APPARATUS



Industrial Notes

Equipment For WPA Projects.—Electrical machinery, apparatus and supplies valued at nearly $10,000,000 went into projects of the Works Progress Administration in the first 26 months of its operation up until September 1, 1937 according to records of the WPA Division of Research, Statistics and Records. All of the purchases for Federal account were by the Procurement Division of the United States Treasury Department after open competitive bidding. As a general rule, the purchases were in comparatively small lots and bid awards went to dealers in the immediate vicinity of the projects. Direction of work at Bonneville, Grand Coulee and in the Tennessee Valley for which extremely large orders for electrical equipment, apparatus and supplies were authorized, are not under the WPA and these purchases are not included in the above totals.

Floodlighting Freight Yards.—The Pennsylvania Railroad is installing 53 General Electric floodlights in the Enola freight yards, west of Harrisburg, Pa., one of the largest yards in the country. Initially type AL-34 incandescent units, equipped with 1000-watt lamps will be installed and later, if more light is desired, 1500-watt lamps will be installed. Groups of 15, 18, 14, and 6 lights will be mounted on towers located in various parts of the yard.

Coast Wire Plant Completed.—Western Insulated Wire, Inc., has completed construction of its plant at 1001 E. 62nd St., Los Angeles. A. D. Nast, Jr., formerly of Sickle, Heath & Nast, Chicago, is president, and E. H. Lewis, formerly design engineer in charge of wire and cable, of General Electric Co., and later general manager of the Hatfield Wire & Cable Co., is vice-president. The company will manufacture all types of rubber covered wire.

New Suspension Insulators.—Two rugged suspension insulators, one of petticoat design and one with a smooth disc, have been announced by the Ohio Brass Co., Mansfield, Ohio. These insulators, known as Huskitypes, are provided with high impact resistance to minimize breakage. The petticoat-type is intended for use on lines which are subject to rock throwing and which demand an insulator with standard flash-over values and full leakage distance. The other type, designed to deflect missiles from its smooth under surface without damaging the insulator, is for use on lines which are subject to gun fire. Although these insulators are special types, they possess the same mechanical and electrical characteristics as the standard O-B types.

Low Loss Molding Material.—The Bakelite Corporation, New York, announces the development of Bakelite polystyrene molding material, which possesses a loss factor of less than .00053, a power factor of less than .0002, and a dielectric constant of 2.60 at 60, 1,000 and 1,000,000 cycles. This new material is said to offer marked advantages for many electrical products and equipment parts. Its dielectric strength is more than 500 volts per mil; its resistivity 10^8 megohm-centimeters; and its arc resistance 240–250 seconds. Tests indicate that no noticeable change occurs in electrical properties with an increase in temperature or humidity. In addition to electrical advantages the new material provides uniformity in molding; freedom from crazing or surface difficulties; permanence of dimension; and high resistance to water, acids and alkalies, with extreme durability and toughness.

Increased Business for Westinghouse.—Orders booked by Westinghouse Electric & Mfg. Company for the nine months ended September 30 amounted to $191,200,758 as compared with $134,148,358 for the same period in 1936, an increase of 43 per cent. Sales billed for the nine months were $154,839,997 as compared with $115,992,637 for the like period in 1936, an increase of 33 per cent.

New Armco Sales Manager.—Murray B. Wilson, associated with the American Rolling Mill Co., Middletown, Ohio, since 1923, has been named sales manager of the New York sales district. He succeeds Cliff Spear, who was forced to curtail activities because of continued ill health.

Clock Industry Large Wire User.—Over 100,000 pounds of copper wire of approximately the diameter of a human hair will be used by the Warren Telechron Company, Ashland, Mass., in the construction of coils for its synchronous electric clocks this year. The wire averages 28,000 feet per pound.

New Okonite Sound Film.—The Okonite Company, Passaic, N. J., has completed a new two-reel sound film showing how rubber insulated wires and cables are made and used. Lowell Thomas is the narrator. It will be shown in 16 mm and 35 mm sizes to those interested in the subject.

Trade Literature

Testing Instruments.—Bulletin A, 4 pp. Describes measuring and testing instruments for the laboratory design and quality control of radio frequency components and materials. Boonton Radio Corporation, Boonton, N. J.

Machining Aluminum.—Booklet, 32 pp. A detailed treatment of the machining of aluminum and aluminum alloys. Aluminum Company of America, Gulf Building, Pittsburgh, Pa.

Teletype Communication.—Booklet, 24 pp. Describes teletype communication systems, for all phases of railroad operation. Teletype Corporation, 1400 Wrightwood Ave., Chicago, Ill.

Capacitors.—Catalog 142. Describes mounting and constructional features of box-type capacitors for correction of low power factor in industrial plants. Power Factor Div., Cornell-Dubilier Electric Corp., South Plainfield, N. J.

Washers and Stampings.—Catalog "Over 20,000 Varieties." Describes diversified products and services available to electrical manufacturers. Wrought Washer Mfg. Co., Milwaukee, Wis.

Switches.—Bulletin 920A, 8 pp. Describes a comprehensive line of remote control switches. Profusely illustrated with drawings and photographs showing details of operation, applications, etc. Automatic Switch Co., 154 Grand St., New York City.

Capacitors.—Bulletin 3582, 8 pp. Describes unit type distribution capacitors for pole mounting developed to meet the demand for small capacity single-phase units. Products Protection Corp., P. O. Box 904, New Haven, Conn.

Motors.—Bulletin, 24 pp. Presents complete data on all types of fractional horsepower motors, repulsion start induction, split phase, capacitor, polyphase, direct current, with suggestions as to how they can be most effectively applied. Century Electric Co., St. Louis, Mo.

Industrial Lighting Equipment.—Catalog 26, 352 pp., loose leaf. The book, in addition to supplying complete commercial data, thoroughly details a vast number of specifications, engineering recommendations, floor layout plans, etc. Benjamin Electric Mfg. Co., Des Plaines, Ill.

Motors.—Bulletin 122, 2 pp. Describes flash-proof, type AA Motors, 2- and 3-phase a-c squirrel cage. Bulletin 124, 2 pp., describes explosion proof, type AA motors, squirrel cage, 2- and 3-phase. Reliance Electric & Engineering Co., 1088 Ivanhoe Road, Cleveland, Ohio.

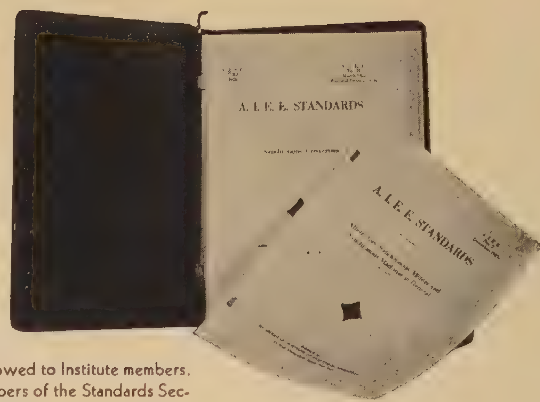
Capacitors.—Bulletin GEA-2561A, 8 pp. Describes Pyranol distribution capacitors, individual pole-type units, class ID, for improving the power factor of feeders. These new units are compact and readily installed with either crossarm mounting or direct bolting to the pole. General Electric Co., Schenectady, N. Y.

Heat Conservation.—Booklet, "Heat," 48 pp. Describes early theories and discoveries concerning the nature of heat, methods of heat transfer, and the development of material designed for insulation and radiation of heat losses. Profusely illustrated with more than 70 charts, photographs and drawings on all phases of the subject. Johns-Manville, 22 E. 40th St., New York City.

Condenser Tubes.—Booklet, 28 pp., "A Study of Tube Corrosion in the Marine and Power Fields." Contains practical information on condenser tube corrosion and its primary causes, together with the most economical remedies. Included are ASTM specifications and interesting description of the process of modern condenser tube manufacture. Chase Brass & Copper Co., Waterbury, Conn.

A.I.E.E. STANDARDS

THE Standards of the American Institute of Electrical Engineers now comprise forty-six sections on electrical machinery and apparatus. They are chiefly devoted to defining terms, conditions, and limits which characterize behavior, with special reference to acceptance tests, and many of them are recognized officially as American Standards.



The Standards available are listed below, together with prices. A discount of 50% is allowed to Institute members. Such discount is not applicable on extra copies unless ordered for other members. Numbers of the Standards Sections should be given when ordering. A binder (illustrated above) for standards is available. Long wearing stiff covers, resembling leather, lettered in gold. Price $1.75 net.

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E.E., have had responsible charge elec des, constr, oprn pwr stations, substations, overhead underground transm; also office bldgs, large indus plants including mech maintenance; investigations, reports stream flow water storage. E-141.

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ELEC SUPT OR DISTR ENGR, exper pub util oprtg, des, constr, valuation, etc., domestic and foreign service. NY State license. Location immaterial. Sales engg or exec pos preferred. E-133.

GRAD E.E., '29, single, 30, seeks permanent connection So. Am. mining co as pwr supt, plant mgr. Now employed, available Feb '38; 3 yrs pwr supt, 2 yrs junior engr, GE test. E-134.

COMMERCIAL ENGR, grad, licensed; 6 yrs engg elec util; 9 yrs rates, budgets, pub contact, advertising, indus promotion. Wishes pos head rate dept or asst to a top util exec. E-139.

M.E.E., B.E.E., Cum Laude, 1937, age 23. Honor man, scholarship, award for outstanding col achievement, Delta Pi Epsilon. Pos desired affording engg exper and advancement. Present residence: NYC. E-125.

E.E., 23, 1936 grad, research induction machines; year's exper oprtg automatic Diesel generating plants. Inventive, resourceful. Present location NY. Go anywhere. E-127.

RECENT GRAD, B.E.E., M.E.E., interested in magnetic circuits and machy; des or research. Publications. Awarded AIEE National First Prize. Tau Beta Pi, Eta Kappa Nu, Grad Fellow. Location, East preferred. E-128.

E.E., B.S., Univ of Denver, 1937, single, 22. Desires pos in indus firm or pub util. Location immaterial. E-129-8951-Chicago.

B.S., E.E., NYU, 1936. Indus E.E., Pratt, 1933. Single, 25. One yr RCA radiotron managerial training course. Desires start in illum or motor field. Location East. Available immed. E-130.

B.S., E.E., Villanova Col, 1934. Exper in pressure gauge assembling and calibrating; also flow meters. Pos with pub util or instrument firm desired. Location, East. Salary secondary. E-136.

E.E., B.S., 1937, honor student, grad study, exper testg machy; now employed; desires pos in pwr transm, circuits or work of similar nature. Salary secondary, future and job more important. E-140.

B.S., E.E., '34, single, 26; 23 mos exper: Util, meter reader, collections, complaint investigator, emergency lineman. Salary and location secondary to opportunity foi training for distr engg. E-135.

ELECTRICIAN-SWBD OPERATOR, married, 31; 14 yrs exper maintenance, instal, oprtg, draftg with mining, ry, pub util, indus concerns. Foreign exper, speaks Spanish. Location East. Permanent pos desired. Tech training. E-137.

E.E., Cornell, 1931; 6 yrs mfg small elec parts and molded plastics. Familiar with factory methods and handling personnel. Employed. Location desired, East. E-131.

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Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Asbestos Covered

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Bare Copper

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
Roebling's Sons Co., John A., Trenton, N. J.
General Cable Corp., New York

Bronze

Copperweld Steel Co., Glassport, Pa.

Copper Covered Steel

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York

Flexible Cord

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Heavy Duty Cord

American Steel & Wire Co. Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Lead Covered (Paper and Var. Cambric Ins.)

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Okonite-Callender Cable Co., Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Magnet

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.

Rubber Insulated

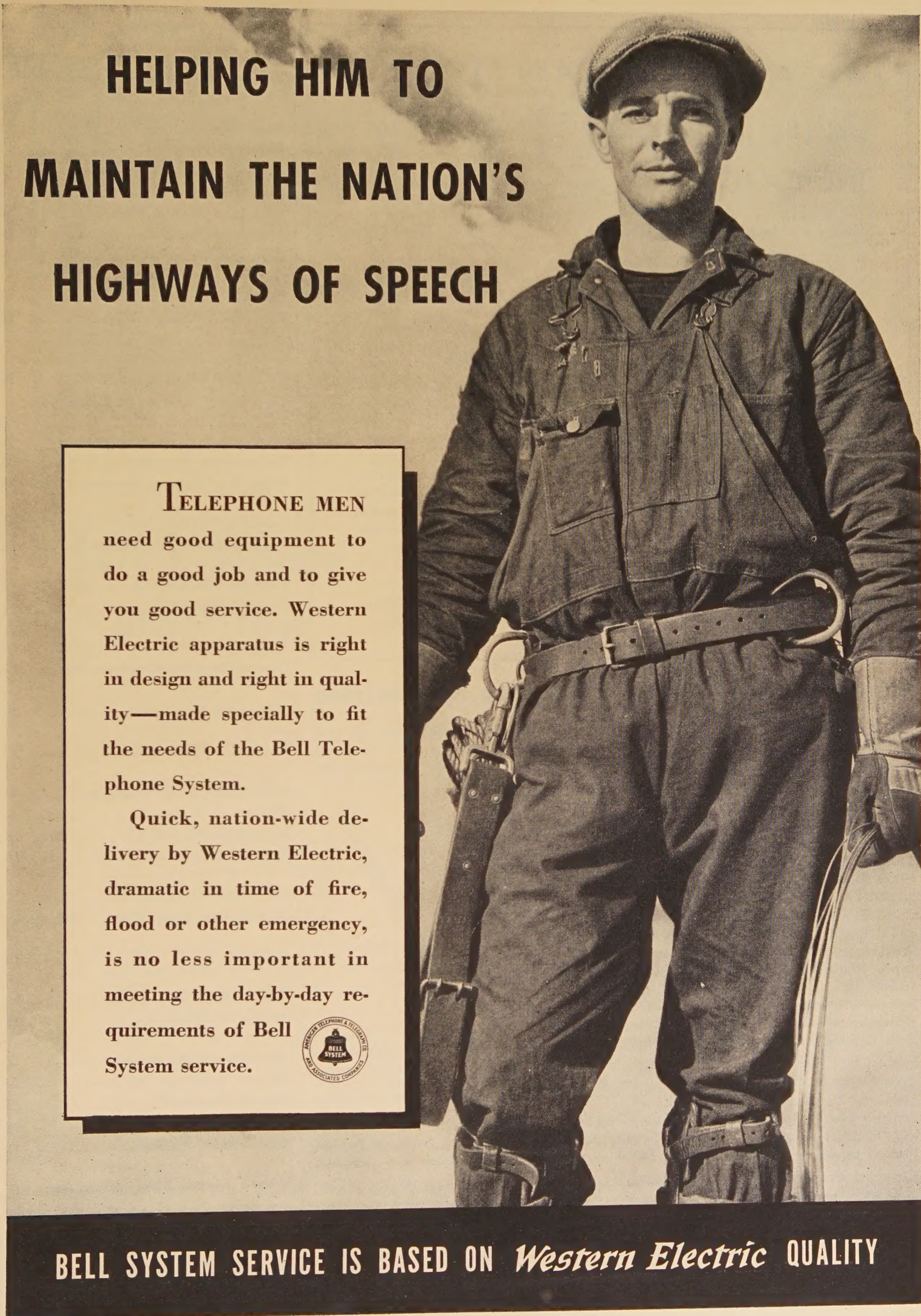
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Tree Wire

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Weatherproof

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N.J.
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.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